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LEVEL II

DEVELOPMENT OF MIL-HDBK-5 DESIGN ALLOWABLE PROPERTIES FOR SEVERAL AEROSPACE MATERIALS

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PAUL E. RUFF
BATTELLE'S COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

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C J Harmsworth

C. L. Harmsworth, Technical Manager
for Engineering and Design Data
Materials Integrity Branch
Systems Support Division
Air Force Wright Aeronautical Laboratory

FOR THE COMMANDER

T D Cooper

T. D. Cooper, Chief
Materials Integrity Branch
Systems Support Division
Air Force Wright Aeronautical Laboratory

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This final report describes a test program to determine MIL-HDBK-5 design allowable properties for 2024-T42 extrusion and Ti-6Al-2Sn-4Zr-2Mo, duplex annealed, sheet.

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PREFACE

This final report was submitted by Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, under Contract F33615-77-C-5036 with the Air Force Wright Aeronautical Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. C. L. Harmsworth (MLSA) was the laboratory project monitor. This report covers the period of work from April 25, 1977, through August 29, 1980. This report was submitted by the author, Mr. Paul E. Ruff, in August 1980.

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SUMMARY

The results of this test program indicated that the existing design values in MIL-HDBK-5C for 2024-T42 extrusion are not appropriate for all thicknesses. Most of the existing "derived" properties, F_{tu}(LT), F_{ty}(LT), F_{cy}, F_{su}, F_{bru}, and F_{bry}, are unconservative above one-inch thickness with some of the existing values unconservative below this thickness. Consequently, new design allowable properties for 2024-T42 extrusion were determined in one-quarter-inch increments through 2½ inches thickness and are presented in Table 10. These new design values were based upon the data obtained from this test program and existing data. The data were analyzed in accordance with MIL-HDBK-5 guidelines.

Based upon the data from this test program and existing data, missing design values for Ti-6Al-2Sn-4Zr-2Mo, duplex annealed, sheet, have been determined. Specifically, design values for F_{cy}, F_{bru}, and F_{bry} have been developed for four thickness ranges for sheet (0.187-inch maximum thickness) and are shown in Table 21. A room temperature E_c value, and an elevated temperature curve, Figure 43, for E_c, were established. Also, an elevated temperature curve, Figure 41, for F_{cy} was also determined.

These new design data have been prepared in MIL-HDBK-5 format to facilitate incorporation in the next MIL-HDBK-5 revision.

LIST OF SYMBOLS

R = reduced ratio, cyclic stress ratio

$\bar{r}$ = mean value of ratios

s = standard deviation

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-1 degrees of freedom

n = number of ratios in sample

RT = room temperature

F_{tu} = ultimate tensile stress (design allowable)

F_{ty} = tensile yield stress (design allowable)

F_{cy} = compressive yield stress (design allowable)

F_{su} = ultimate shear stress (design allowable)

F_{bru} = ultimate bearing stress (design allowable)

F_{bry} = bearing yield stress (design allowable)

E = modulus of elasticity in tension

E_c = modulus of elasticity in compression

TUS = tensile ultimate strength

TYS = tensile yield strength

CYS = compressive yield strength

SUS = shear ultimate strength

L = longitudinal

LT = long transverse

BUS = bearing ultimate strength

BYS = bearing yield strength

ksi = thousands of pounds per square inch

psi = pounds per square inch

INTRODUCTION

The Military Standardization Handbook, MIL-HDBK-5, is recognized as the primary source for design allowable data required by the Department of Defense (DoD), other Government agencies, and aerospace contractors responsible for aerospace vehicle design. The Handbook contains design allowable data on metallic materials, fasteners, joints, and other structural elements. The maintenance of this document is achieved through the cooperative efforts of the Air Force, Navy, Army, Federal Aviation Agency (FAA), and industrial users and suppliers of metallic aerospace materials. The DoD has designated the Air Force as the activity responsible for preparing this Handbook. As such, the Air Force Wright Aeronautical Laboratory (AFWAL) has contracted with Battelle's Columbus Laboratories (BCL) to provide the planning, coordination, implementation, and testing necessary to develop and maintain current design allowable data and other related information in MIL-HDBK-5.

Other final reports have described in detail the functional and technical activities performed by BCL in connection with the MIL-HDBK-5 program. Since the functional as well as some of the technical activities are somewhat repetitive from year to year, this final report describes an experimental test program to develop certain MIL-HDBK-5 design allowable properties for several materials.

Most of the design allowable properties in MIL-HDBK-5 are determined from existing data. However, frequently data are lacking or inadequate to establish needed design properties. Data may be lacking for important design properties even though an alloy may have been used in the aerospace industry for many years. Sometimes it is desirable to verify existing design values in the Handbook. In addition, new heat treatments and new product forms may be developed for an existing alloy, thereby creating a need for applicable design properties. Also, MIL-HDBK-5 guidelines are continuously revised to provide for the inclusion of new types of data, such as fracture toughness and fatigue-crack-propagation data. For these reasons testing is often necessary to supplement data available from the literature.

Based upon interest expressed by the MIL-HDBK-5 Coordination Committee, availability of existing mechanical property data, and the availability of test material, two materials, 2024-T42 aluminum extrusion and Ti-6Al-2Sn-4Zr-2Mo, duplex annealed sheet were selected for this test program.

OBJECTIVE

The objective of this test program was : (1) to verify the existing room temperature design values for 2024-T42 extrusion and (2) to determine missing design values for Ti-6Al-2Sn-4Zr-2Mo, duplex annealed, sheet.

EXPERIMENTAL PROCEDURES

2024-T42 Aluminum Alloy Extrusion

Background - MIL-HDBK-5 currently contains in Table 3.2.3.0(j) a single set of design values which are applicable to all thicknesses for 2024-T42 extrusions. From this same table it is evident that the F_{tu}(LT)/F_{tu}(L) and the F_{ty}(LT)/F_{ty}(L) ratios decrease significantly with increasing thickness for 2024-T4, T3510, and T3511 extrusions. It is believed that these ratios should follow this same trend for the T42 temper.

Investigations revealed that design values for the T42 temper first appeared in MIL-HDBK-5, dated March 1959, which included items approved at meetings 1 through 16. However, a review of the agenda and minutes of these meeting did not reveal the basis for these design values. It appears that the bearing ratios were based upon a "rule-of-thumb", which was sometimes used for aluminum alloys at that time, as follows: $F_{bru}/F_{tu}(e/D = 1.5) = 1.5$, $F_{bru}/F_{tu}(e/D = 2.0) = 1.9$, $F_{bry}/F_{ty}(e/D = 1.5) = 1.4$, and $F_{bry}/F_{ty}(e/D = 2.0) = 1.6$. Item 66-20, "Derived Properties for Heat-Treated-By-User Tempers", was established at the 33rd meeting. Proposals containing design allowables were to be prepared based upon a forthcoming Air Force Materials Laboratory report, providing additional data could be obtained. Since additional data were not available, this item was cancelled.

A literature search revealed that tensile, compression, shear, and bearing data for 2024-T42 extrusions were contained in reference (1), presumably the report mentioned in Item 66-20. However, only five lots were tested in reference (1). Consequently, testing of additional lots was required in order to comply with MIL-HDBK-5 guideline requirements for the determination of design values. Since the basis for existing design values for the T42 temper could not be determined and the likelihood that the existing values were based upon limited data, it was desirable to conduct a test program to resolve this matter.

Test Plan - As defined in Chapter 1, Section 1.4.1.3 of MIL-HDBK-5, derived values are those room temperature mechanical property values that are established through their relationship to directly calculated (or specification) values for room temperature F_{tu} and F_{ty}. The guidelines for the presentation of data are described in Chapter 9, Section 9.2.9.1, of MIL-HDBK-5 and requires at least ten pairs of measurements, each representing a single lot of material.

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(1) Brownhill, D.J., et al, "Mechanical Properties, Including Fracture Toughness and Fatigue, and Resistance to Stress Corrosion Cracking, of Stress-Relieved Stretched Aluminum Alloy Extrusions", AFML-TR-68-34, Alcoa, February 1978, MCIC No. 71819.

Table 1 shows the test plan to acquire the necessary data. Room temperature tensile, compression, and bearing data for five lots (heats) were available in reference (1). Shear data were available for three lots in longitudinal direction and two lots in long transverse direction in reference (1). The data in reference (1) covered the following thicknesses: 0.064, 0.083, 0.430 0.500, and 2.562 inches. Therefore, to span the thickness range through 2.562 inches, seven lots of extrusions preferably between 0.500 and 2.562 inches in thickness were needed. A request was made to aerospace companies participating in the MIL-HDBK-5 program for test material. Since the T42 temper is a "heat-treated-by-user temper", it was believed that representative T42 material would be obtained from aerospace companies.

Material - Only the Boeing Company could supply test material. Seven heats of extrusions in various thicknesses were received from Boeing as follows:

Size, in.	Shape	Supplier	Lot No.
1 x 2-1/4	Rectangle	Alcoa	389719
1-1/4 x 2-1/4	Rectangle	Alcoa	---
1-1/2 x 2-1/2	Rectangle	Alcoa	356925
1-3/4 x 3	Rectangle	Martin Marietta	89/551089
2 x 2	Square	Alcoa	354753
5/16 x 2 x 3	Angle	Alcoa	E93641A
---	Zee	Conalco	93162P-N

The test material was produced to QQ-A-220/3 and represented three suppliers. Boeing heat treated the extrusions to the T42 temper.

Test Specimens - Since single tests were used in reference (1). single tests were utilized in this program so as to avoid bias of the data. The configurations of the test specimens are shown in Figures 1 through 4. Because of the size and configuration of the extrusions, subsize test specimens were required. In order to minimize test variables, the configuration and size of the test specimens were similar to those used in reference (1). Longitudinal specimens were machined from the following locations:

Thickness, in.	Thickness	Location of Axis of Specimen With Respect To Thickness (T) and Width (W) of Predominant Section — Width $\leq$ 1.500 in.	>1.500 in.
< 0.500	T/2	---	---
0.500 to 1.500 incl.	T/2	W/2	W/4
> 1.500	T/4	---	W/4

All long transverse specimens were taken from the T/2 location. These specimen locations were the same as those used in reference (1). Specific locations of the test specimens are shown in Figures 5 through 18.

Testing - All specimens were tested at room temperature in the "as received" T42 temper in accordance with the procedures described in Appendix A. The results of the mechanical property tests are shown in Table 2. All lots conformed to the minimum longitudinal tensile properties specified in QQ-A-200/3.

Analysis - As previously indicated, derived values refer to those room temperature mechanical property values that are established through their relationships to directly calculated (or specification) values for room temperature F_{tu} and F_{ty}. The procedure is applicable to F_{cy}, F_{su}, F_{bru}, and F_{bry} and involves the pairing of SUS and BUS measurements with TUS measurements for which F_{tu} has been established. Likewise, CYS and BYS measurements are paired with TYS measurements for which F_{ty} has been established. Tensile properties in grain directions not covered by specification are also derived in a similar manner.

Using the above relationships, reduced ratios for the various "unknown" properties were determined using the computational procedure described in Chapter 9, Section 9.2.9.2 of MIL-HDBK-5. The specified test direction for extrusions is longitudinal. Consequently, the individual test values for longitudinal and long transverse compression yield and bearing yield strength were paired with the corresponding individual test values for longitudinal tensile yield strength. Similarly, the longitudinal and long transverse shear and bearing ultimate values were paired to the corresponding longitudinal tensile ultimate values. Long transverse tensile yield and ultimate strength values were paired to corresponding longitudinal tensile properties. The tensile, compression, shear and bearing ratios are shown in Table 3 for the material tested. Reduced ratios were computed using the following equation when the ratios did not vary with thickness:

$$R = \bar{r} - \frac{t_{0.95}s}{\sqrt{n}} ,$$

where R = reduced ratio

$\bar{r}$ = average of n ratios

s = standard deviation of the ratios

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-1 degrees of freedom

n = number of ratios.

When the ratio varied with thickness, the following equation was used in regression analysis:

$$R = \bar{r}' - t_{0.95}s'\sqrt{\frac{1}{n} + \frac{\left(x_o - \Sigma x/n\right)^2}{\left(\Sigma x^2\right) - \left(\Sigma x\right)^2/n}} ,$$

where R = reduced ratio

$\bar{r}'$ = mean ratio for specific thickness, x_o

s' = standard error of estimate

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-2 degrees of freedom

n = number of ratios

x_o = specific thickness

x = individual thickness values for ratios.

A computer program was used to perform the analysis. The results are shown in Tables 4 through 8. A plot of ratio versus thickness is depicted in Figures 19 through 28. A summary of the computed reduced ratios is presented in Table 9.

All of the reduced ratios, except CYS(L)/TYS(L) and SUS(L)/TUS(L), exhibited regression with increasing thickness. Due to the severity of the regression for some properties, it was decided to present design values in 1/4-inch increments up to 2-1/2 inches in thickness. The reduced ratios in Table 9 were multiplied by the TUS(L) or TYS(L) specification value to obtain the design values shown in Table 10. Normally, shear and bearing allowables are not shown by grain direction. The lower reduced ratio for either grain direction was used to compute the design value for shear ultimate strength. Existing Table 3.2.3.0(j) has been revised to delete the T42 temper and the revision is designated Table 3.2.3.0(j_1) as illustrated in Table 11.

TABLE 1. TEST PLAN FOR 2024-T42 EXTRUSIONS

Thickness, inches	Grain Direction	Tensile	Compression	Shear	Bearing e/D = 1.5	Bearing e/D = 2/0
0.064	L	x*	x	-	x	x
	LT	x	x	-	x	x
0.083	L	x	x	-	x	x
	LT	x	x	-	x	x
0.313	L	o**	o	o	o	o
	LT	o	o	o	o	o
0.430	L	x	x	x	x	x
	LT	x	x	x	x	x
0.500	L	x	x	x	x	x
	LT	x	x		x	x
1.000	L	o	o	o	o	o
	LT	o	o	o	o	o
1.250	L	o	o	o	o	o
	LT	o	o	o	o	o
1.500	L	o	o	o	o	o
	LT	o	o	o	o	o
1.700	L	o	o	o	o	o
	LT	o	o	o	o	o
1.750	L	o	o	o	o	o
	LT	o	o	o	o	o
2.000	L	o	o	o	o	o
	LT	o	o	o	o	o
2.562	L	x	x	x	x	x
	LT	x	x	x	x	x

* X-data available in reference (1).

** O-data to be obtained from testing.

TABLE 2. MECHANICAL PROPERTIES OF 2024-T42 EXTRUSIONS

Section Thickness, Inches	Location	Grain Direction	Tensile			Comp. Yield Strength, ksi	Shear Ultimate Strength, ksi	Bearing e/D = 1.5		Bearing e/D = 2.0	
			Ultimate Strength, ksi	Yield Strength, ksi	Elongation, %			Ultimate Strength, ksi	Yield Strength, ksi	Ultimate Strength, ksi	Yield Strength, ksi
0.313	T/2, W/2	L	64.0	41.9	26.0	44.5	45.1	102.9	67.1	126.6	86.6
0.313	T/2	LT	67.3	42.7	14.0	45.3	41.8	-	-	-	-
1.000	T/2, W/4	L	67.5	42.7	24.0	45.8	42.9	102.9	71.1	128.7	84.7
1.000	T/2	LT	62.1	40.4	14.0	43.5	40.8	-	-	-	-
1.250	T/2, W/4	L	80.7	55.6	18.0	58.1	43.0	109.0	70.4	136.8	90.1
1.250	T/2	LT	70.1	46.5	20.0	49.7	43.7	-	-	-	-
1.500	T/2, W/4	L	82.2	57.3	18.0	59.3	41.4	107.9	69.7	139.1	86.0
1.500	T/2	LT	67.7	46.5	12.0	50.2	43.0	-	-	-	-
1.700	T/4, W/4	L	77.6	52.7	16.0	53.6	41.0	108.7	68.9	131.0	86.4
1.700	T/2	LT	63.5	45.2	8.0	48.8	40.6	-	-	-	-
1.750	T/4, W/4	L	79.2	55.0	14.0	57.6	40.7	104.7	66.4	128.7	86.7
1.750	T/2	LT	63.8	45.2	7.0	47.9	40.9	-	-	-	-
2.000	T/4, W/4	L	78.7	54.2	20.0	55.8	42.3	90.6	58.4	111.9	74.8
2.000	T/2	LT	63.7	43.3	6.0	46.2	41.6	-	-	-	-

TABLE 3. TENSILE, COMPRESSION, SHEAR, AND BEARING RATIOS FOR 2024-T42 EXTRUSIONS

Section Thickness, Inches	Location	TUS(LT)/TUS(L)	TYS(LT)/TYS(L)	CYS(L)/TYS(L)	CYS(LT)/TYS(L)	SUS(L)/TUS(L)	SUS(LT)/TUS(L)	e/D = 1.5 BUS(L)/TUS(L)	e/D = 1.5 BYS(L)/TYS(L)	e/D = 2.0 BUS(L)/TUS(L)	e/D = 2.0 BYS(L)/TYS(L)
0.313	T/2, W/2			1.062		0.705		1.608	1.601	1.978	2.067
	T/2	1.052	1.019		1.081		0.653				
1.000	T/2, W/4			1.073		0.636		1.524	1.665	1.907	1.984
	T/2	0.920	0.946		1.019		0.604				
1.250	T/2, W/4			1.045		0.533		1.351	1.266	1.695	1.621
	T/2	0.869	0.836		0.894		0.542				
1.500	T/2, W/4			1.028		0.504		1.313	1.208	1.692	1.490
	T/2	0.824	0.806		0.870		0.523				
1.700	T/4, W/4			1.017		0.528		1.401	1.307	1.688	1.639
	T/2	0.818	0.858		0.926		0.523				
1.750	T/4, W/4			1.047		0.514		1.322	1.207	1.625	1.576
	T/2	0.806	0.822		0.871		0.516				
2.000	T/4, W/4			1.030		0.537		1.151	1.077	1.422	1.380
	T/2	0.809	0.799		0.852		0.529				

TABLE 4. LIST OF RATIOS VERSUS THICKNESS FOR

2024-T42 EXTRUSION

	TUS(LT)/TUS(L)	TYS(LT)/TYS(L)	THICKNESS	
1	1.063	.978	.064	(from ref.(1))
2	1.015	1.019	.083	(from ref.(1))
3	1.052	1.019	.313	
4	.996	.990	.430	(from ref.(1))
5	.897	.872	.500	(from ref.(1))
6	.920	.946	1.000	
7	.869	.836	1.250	
8	.824	.806	1.500	
9	.818	.858	1.700	
10	.806	.822	1.750	
11	.809	.799	2.000	
12	.747	.774	2.562	(from ref.(1))

TABLE 4. CONTINUED

STATISTICS FOR THE PLOT OF TUS(LT)/TUS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.0367 -.1235 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .1072

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0358

R-SQUARED STATISTIC= 88.87

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.0046 AND 1.0687
AND ON B(2) ARE -.1472 AND -.0997

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.006	.978
.500	.975	.951
.750	.944	.924
1.000	.913	.894
1.250	.882	.863
1.500	.851	.830
1.750	.821	.795
2.000	.790	.761
2.250	.759	.726
2.500	.728	.690
2.750	.697	.654
3.000	.666	.617

TABLE 4. CONCLUDED

STATISTICS FOR THE PLOT OF TYS(LT)/TYS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.0023 -.0995 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .0913

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0423

R-SQUARED STATISTIC= 78.57

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE .9644 AND 1.0402
AND ON B(2) ARE -.1276 AND -.0715

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	.977	.945
.500	.953	.925
.750	.928	.904
1.000	.903	.881
1.250	.878	.855
1.500	.853	.828
1.750	.828	.799
2.000	.803	.770
2.250	.778	.739
2.500	.754	.708
2.750	.729	.677
3.000	.704	.646

TABLE 5. LIST OF RATIOS VERSUS THICKNESS FOR 2024-T42 EXTRUSION

	CYS(L)/TYS(L)	CYS(LT)/TYS(L)	THICKNESS	
1	1.007	1.067	.064	(from ref.(1))
2	1.058	1.055	.083	(from ref.(1))
3	1.062	1.081	.313	
4	1.025	1.050	.430	(from ref.(1))
5	1.007	0.000	.500	(from ref.(1))
6	1.073	1.019	1.000	
7	1.045	.894	1.250	
8	1.028	.870	1.500	
9	1.017	.926	1.700	
10	1.047	.871	1.750	
11	1.030	.852	2.000	
12	.976	.814	2.562	(from ref.(1))

TABLE 5. CONTINUED

STATISTICS FOR THE PLOT OF CYS(L)/TYS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.0446 -.0122 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .0275

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0269

R-SQUARED STATISTIC= 4.73

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.0206 AND 1.0687
AND ON B(2) ARE -.0300 AND .0056

SIGNIFICANT REGRESSION NO

MEAN RATIO= 1.031

REVISED T STATISTIC= 1.796

REDUCED RATIO= 1.017

TABLE 5. CONCLUDED

STATISTICS FOR THE PLOT OF CYS(LT)/TYS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.0647 -.1132 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .1304

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0337

R-SQUARED STATISTIC= 86.75

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.0521 AND 1.1172
AND ON B(2) ARE -.1365 AND -.0900

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.056	1.028
.500	1.028	1.004
.750	1.000	.979
1.000	.971	.953
1.250	.943	.924
1.500	.915	.895
1.750	.887	.863
2.000	.858	.831
2.250	.830	.798
2.500	.802	.765
2.750	.773	.732
3.000	.745	.698

TABLE 6. LIST OF RATIOS VERSUS THICKNESS FOR 2024-T42 EXTRUSION

	SUS(L)/TUS(L)	SUS(LT)/TUS(L)	THICKNESS	
1	.705	.653	.313	
2	.536	.525	.430	(from ref.(1))
3	.494	.000	.500	(from ref.(1))
4	.636	.604	1.000	
5	.533	.542	1.250	
6	.504	.523	1.500	
7	.528	.523	1.700	
8	.514	.516	1.750	
9	.537	.529	2.000	
10	.476	.469	2.562	(from ref.(1))

TABLE 6. CONTINUED

STATISTICS FOR THE PLOT OF SUS(L)/TUS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = .6140 -.0521 X (THICKNESS)

NUMBER OF DATA= 10

STANDARD DEVIATION OF Y = .0703

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0623

R-SQUARED STATISTIC= 21.45

95 PERCENT T FACTOR= 1.860

95 PERCENT CONF.
LIMITS ON B(1) ARE .5370 AND .6910
AND ON B(2) ARE -.1041 AND .0000

SIGNIFICANT REGRESSION NO

MEAN RATIO= .546

REVISED T STATISTIC= 1.833

REDUCED RATIO= .506

TABLE 6. CONCLUDED

STATISTICS FOR THE PLOT OF SUS(LT)/TUS(L)
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = .6206 -.0562 X (THICKNESS)

NUMBER OF DATA= 9

STANDARD DEVIATION OF Y = .0540

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0377

R-SQUARED STATISTIC= 51.29

95 PERCENT T FACTOR= 1.965

95 PERCENT CONF.
LIMITS ON B(1) ARE .5645 AND .6771
AND ON B(2) ARE -.0926 AND -.0199

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	.607	.558
.500	.593	.552
.750	.579	.545
1.000	.565	.536
1.250	.551	.525
1.500	.536	.511
1.750	.522	.494
2.000	.508	.475
2.250	.494	.454
2.500	.480	.433
2.750	.466	.411
3.000	.452	.388

TABLE 7. LIST OF RATIOS VERSUS THICKNESS FOR 2024-T42 EXTRUSION

	BUS(L)/TUS(L)1.5	BYS(L)/TYS(L)1.5	THICKNESS
1	1.597	1.692	.064 (from ref.(1))
~~2~~	~~1.489~~	~~1.779~~	~~.083 (from ref.(1))~~
3	1.608	1.601	.313
~~4~~	~~1.392~~	~~1.465~~	~~.430 (from ref.(1))~~
5	1.347	1.347	.500 (from ref.(1))
~~6~~	~~1.524~~	~~1.655~~	~~1.000~~
7	1.351	1.266	1.250
~~8~~	~~1.313~~	~~1.208~~	~~1.500~~
9	1.401	1.307	1.700
~~10~~	~~1.322~~	~~1.287~~	~~1.750~~
11	1.151	1.077	2.000
~~12~~	~~1.381~~	~~1.299~~	~~2.562 (from ref.(1))~~

TABLE 7. CONTINUED

STATISTICS FOR THE PLOT OF BUS(L)/TUS(L)1.5
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.5311 -.1200 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .1335

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0942

R-SQUARED STATISTIC= 50.20

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.4467 AND 1.6155
AND ON B(2) ARE -.1825 AND -.0574

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.501	1.429
.500	1.471	1.409
.750	1.441	1.387
1.000	1.411	1.362
1.250	1.381	1.331
1.500	1.351	1.296
1.750	1.321	1.257
2.000	1.291	1.216
2.250	1.261	1.174
2.500	1.231	1.131
2.750	1.201	1.087
3.000	1.171	1.042

TABLE 7. CONCLUDED

STATISTICS FOR THE PLOT OF BYS(L)/TYS(L)1.5
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.6446 -.2146 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .2258

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .1474

R-SQUARED STATISTIC= 57.37

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.5126 AND 1.7767
AND ON B(2) ARE -.3124 AND -.1168

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.591	1.478
.500	1.537	1.441
.750	1.484	1.399
1.000	1.430	1.352
1.250	1.376	1.298
1.500	1.323	1.236
1.750	1.269	1.169
2.000	1.215	1.098
2.250	1.162	1.025
2.500	1.108	.951
2.750	1.054	.875
3.000	1.001	.739

TABLE 8. LIST OF RATIOS VERSUS THICKNESS FOR 2024-T42 EXTRUSION

	BUS(L)/TUS(L)2.0	BYS(L)/TYS(L)2.0	THICKNESS
1	1.894	1.953	.064 (from ref.(1))
~~2~~	~~1.674~~	~~2.106~~	~~.093 (from ref.(1))~~
3	1.978	2.067	.313
~~4~~	~~1.727~~	~~1.797~~	~~.438~~ (from ref.(1))
5	1.614	1.646	.500 (from ref.(1))
~~6~~	~~1.507~~	~~1.984~~	~~1.000~~
7	1.695	1.621	1.250
~~8~~	~~1.692~~	~~1.498~~	~~1.500~~
9	1.683	1.639	1.700
~~10~~	~~1.625~~	~~1.576~~	~~1.750~~
11	1.422	1.380	2.000
~~12~~	~~1.639~~	~~1.569~~	~~2.552 (from ref.(1))~~

TABLE 8. CONTINUED

STATISTICS FOR THE PLOT OF BUS(L)/TUS(L)2.0
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.8547 -.1264 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .1545

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .1198

R-SQUARED STATISTIC= 39.91

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.7574 AND 1.9720
AND ON B(2) ARE -.2059 AND -.0469

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.833	1.741
.500	1.802	1.723
.750	1.770	1.701
1.000	1.738	1.675
1.250	1.707	1.643
1.500	1.675	1.605
1.750	1.643	1.562
2.000	1.612	1.517
2.250	1.580	1.469
2.500	1.549	1.421
2.750	1.517	1.371
3.000	1.485	1.322

TABLE 8. CONCLUDED

STATISTICS FOR THE PLOT OF BYS(L)/TYS(L)2.0
VERSUS THICKNESS FOR
2024-T42 EXTRUSION

REGRESSED LINE IS
Y = 1.9979 -.2300 X (THICKNESS)

NUMBER OF DATA= 12

STANDARD DEVIATION OF Y = .2394

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .1535

R-SQUARED STATISTIC= 58.89

95 PERCENT T FACTOR= 1.812

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.8503 AND 2.1253
AND ON B(2) ARE -.3319 AND -.1282

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.250	1.930	1.813
.500	1.873	1.772
.750	1.815	1.728
1.000	1.758	1.677
1.250	1.700	1.618
1.500	1.643	1.553
1.750	1.585	1.481
2.000	1.528	1.406
2.250	1.470	1.328
2.500	1.413	1.249
2.750	1.355	1.169
3.000	1.296	1.088

TABLE 9. COMPUTED REDUCED RATIOS* FOR 2024-T42 EXTRUSIONS

Property Ratio	Ratio	Thickness, inches <0.249	0.250-0.499	0.500-0.749	0.750-0.999	1.000-1.249	1.250-1.499	1.500-1.749	1.750-1.999	2.000-2.249	2.250 2.499
TUS(LT)/TUS(L)	--	0.978	0.951	0.925	0.894	0.863	0.830	0.796	0.761	0.726	0.690
TYS(LT)/TYS(L)	--	0.945	0.925	0.904	0.881	0.855	0.828	0.799	0.770	0.739	0.708
CYS(L)/TYS(L)	--	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017
CYS(LT)/TYS(L)	--	1.028	1.004	0.979	0.953	0.924	0.895	0.863	0.831	0.798	0.765
SUS(L)/TUS(L)	--	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506
SUS(LT)/TUS(L)	--	0.558	0.552	0.545	0.536	0.525	0.511	0.494	0.475	0.454	0.433
BUS(L)/TUS(L)	1.5	1.429	1.409	1.387	1.362	1.331	1.296	1.257	1.216	1.174	1.131
BYS(L)/TYS(L)	1.5	1.478	1.441	1.399	1.352	1.298	1.236	1.169	1.098	1.025	0.951
BUS(L)/TUS(L)	2.0	1.741	1.723	1.70[illegible]	1.675	1.643	1.605	1.562	1.517	1.469	1.421
BYS(L)/TYS(L)	2.0	1.813	1.772	1.72[illegible]	1.677	1.618	1.553	1.481	1.406	1.328	1.249

* Underlined ratios used to compute design values.

TABLE 10. PROPOSED MIL-HDBK-5 TABLE 3.2.3.0(j_2)

TABLE 3.2.3.0(j_2). Design Mechanical and Physical Properties of 2024 Aluminum Alloy (Extrusions) - Continued

Specification	QQ-A-200/3									
Form	Extruded, bars, rods, and shapes									
Condition	T42[a]									
Cross-sectional area, in.^{2}	<25									
Thickness or diameter, in.	≤0.249	0.250-0.499	0.500-0.749	0.750-0.999	1.000-1.249	1.250-1.499	1.500-1.749	1.750-1.999	2.000-2.249	2.250-2.499
Basis	S	S	S	S	S	S	S	S	S	S
Properties:										
F_{tu}, ksi:										
L	57	57	57	57	57	57	57	57	57	57
LT	55	54	52	51	49	47	45	43	41	39
F_{ty}, ksi:										
L	38	38	38	38	38	38	38	38	38	38
LT	36	35	34	33	32	3.	30	29	28	27
F_{cy}, ksi:										
L	38	38	38	38	38	38	38	38	38	38
LT	39	38	37	36	35	34	33	31	30	29
F_{su}, ksi	29	29	29	29	29	29	28	27	26	24
F_{bru}[b], ksi:										
(e/D = 1.5)	81	80	79	77	76	74	71	69	67	64
(e/D = 2.0)	99	98	97	95	93	91	89	86	83	81
F_{bry}[b], ksi:										
(e/D = 1.5)	56	55	53	51	49	47	44	41	39	36
e/D = 2.0)	69	67	65	63	61	59	56	53	50	47
e, percent:										
L	12	12	12	10	10	10	10	10	10	10
LT	...	...	...	...	...	...	...	...	...	...
E, 10^3 ksi	10.8									
E_c, 10^3 ksi	11.0									
G, 10^3 ksi	4.1									
μ	0.33									
C, K, and α	See Figure 3.2.3.0.									

[a]These allowables apply when samples of material supplied in the O or F temper are heat treated to demonstrate response to heat treatment. Properties obtained by the user however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

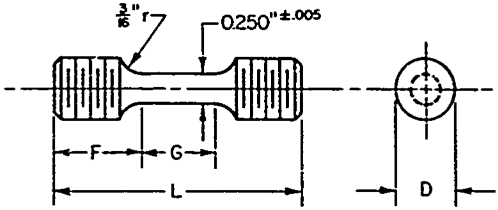
[b]Bearing values are "dry pin" values per Section 1.4.7.1.

TABLE 11. PROPOSED MIL-HDBK-5 TABLE 3.2.3.0(J_1)

TABLE 3.2.3.0(J_1). *Design Mechanical and Physical Properties of 2024 Aluminum Alloy (Extrusions)*

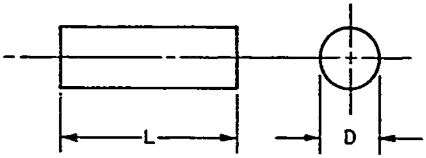
Specification	QQ-A-200/3																
Form	Extruded bars, rods, and shapes																
Temper	T4, T3510 and T3511														T81, T8510 and T8511		
Thickness, in.	<0.249		0.250-0.499		0.500-0.749		0.750-1.499		1.500-2.999		3.000-4.499		1.500-2.999	3.000-4.499	0.050-0.249	0.250-1.499	1.500-4.500
Cross-sectional area, in.²	<20								<25				>25, <32		<20		<32
Basis	A	B	A	B	A	B	A	B	A	B	A	B	S	S	S	S	S
Mechanical properties																	
F_{tu}, ksi																	
L	57	61	60	62	60	62	65	70	70	74	70	74	68	68	64	66	66
LT	54	58	56	57	54	56	56	60	55	58	54	57	51	52	64	64	61
F_{ty}, ksi:																	
L	42	47	44	47	44	47	46	54	52	54	52	54	48	48	56	58	58
LT	37	41	38	40	37	39	37	43	39	41	39	41	36	36	55	57	57
F_{cy}, ksi:																	
L	34	38	37	39	38	40	41	48	49	50	49	51	45	45	57	59	59
LT	41	45	41	44	40	43	40	47	42	44	41	43	39	38	57	59	59
F_{su}, ksi	29	31	31	32	30	33	33	35	34	36	33	35	33	32	35	36	36
F_{bru}, ksi:																	
(e/D=1.5)	84	90	78	81	78	80	84	90	88	93	86	91	86	84	94	96	92
(e/D=2.0)	108	114	98	101	97	101	105	113	111	118	109	115	108	106	123	123	117
F_{bry}, ksi:																	
(e/D=1.5)	61	68	55	59	55	59	57	67	63	66	62	65	59	57	79	82	82
(e/D=2.0)	71	79	67	71	67	71	69	81	77	80	75	78	71	69	93	96	96
e, percent (S basis):																	
L	12	.	12		12		10		10	.	10		8	8	4	5	5
LT	...	...	6[b]	..	6	.	5		2		2	.	..	...	...	...	...
E, 10^3 ksi	10.8																
E_c, 10^3 ksi	11.0																
G, 10^3 ksi	4.1																
μ	0.33																
ω, lb/in.³	0.100																
C, K and α	See Figure 1.2.1.0																

[a] Bearing values are "dry pin" values per Section 1.4.7.1



TYPE	L	G	F	D	THREAD
1	2"	5/8"	11/16"	1/2"	1/2 - 13 NC
2	2 1/4"	5/8"	13/16"	1/2"	1/2 - 13 NC
3	2 1/2"	5/8"	15/16"	1/2"	1/2 - 13 NC
4	2 1/2"	5/8"	15/16"	3/8"	3/8 - 16 NC
A-1209	3"	1 1/4"	7/8"	1/2"	1/2 - 13 NC

Figure 1. Tensile Specimen



Note. Ends to be flat and parallel to within
00002" of centerline

TYPE	L	D
1	1 1/2"	.500"
2	1"	.313"

Figure 2. Compression Specimen

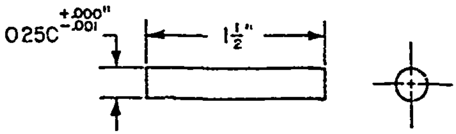
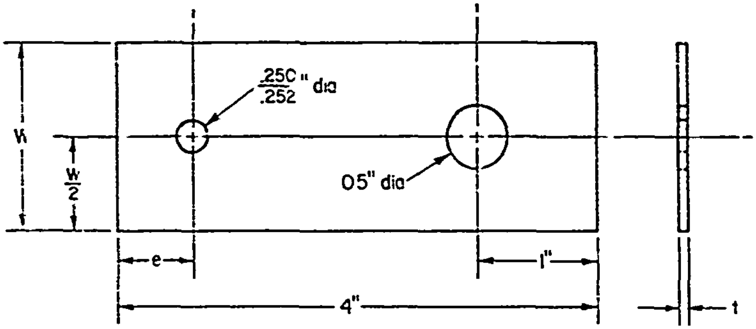


Figure 3. Shear Specimen



TYPE	W	e e/D = 1.5	e e/D = 2.0	t
1	1"	.375	.500	.063"
2	1 1/8"	.375	.500	.074"
3	1 1/4"	.375	.500	.074"
4	1 1/2"	.375	.500	.074"

Figure 4. Bearing Specimen

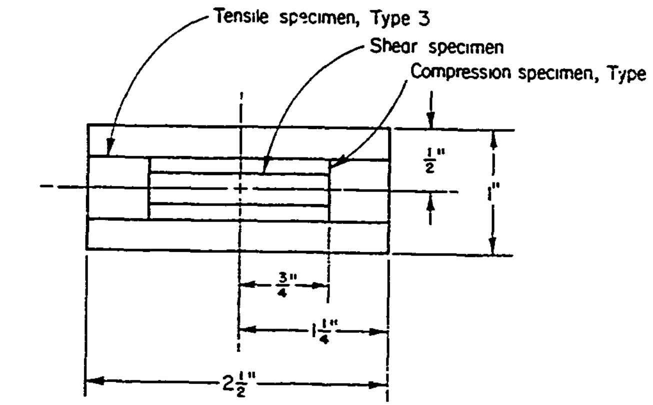


Figure 5. Location of Long Transverse Specimens
For 1" x 2-1/2" Bar

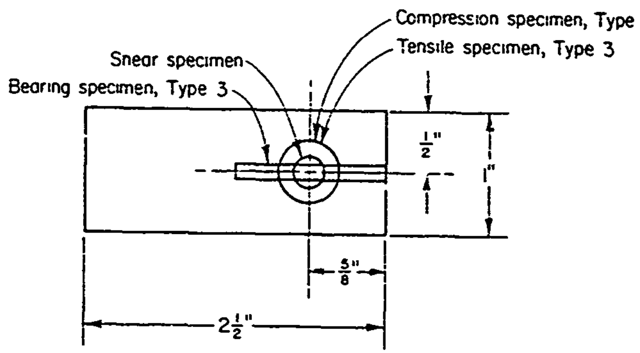


Figure 6. Location of Longitudinal Specimens
For 1" x 2-1/2" Bar

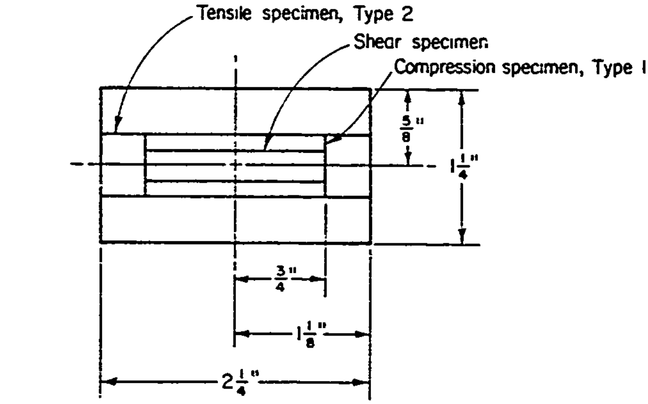


Figure 7. Location of Transverse Specimens
For 1-1/4" x 2-1/4" Bar

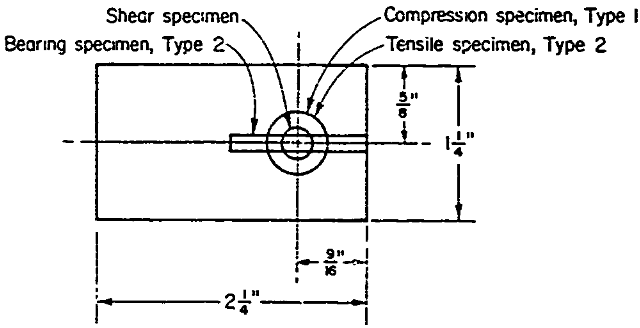


Figure 8. Location of Longitudinal Specimens
For 1-1/4" x 2-1/4" Bar

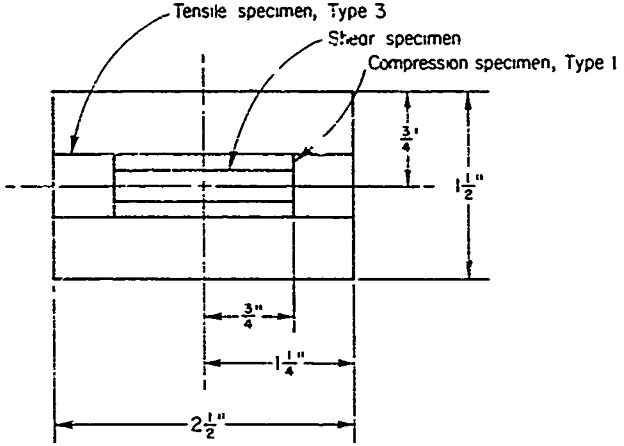


Figure 9. Location of Long Transverse Specimens
For 1-1/2" x 2-1/2" Bar

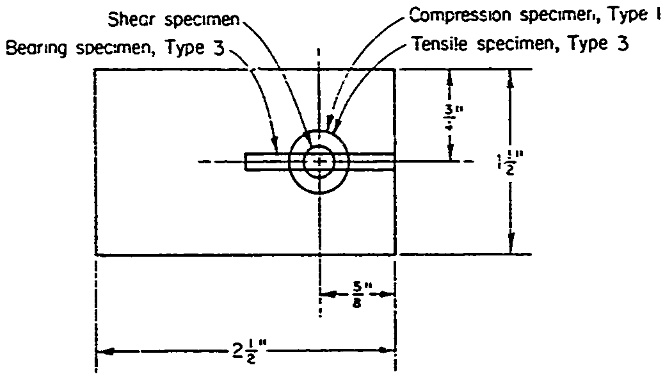


Figure 10. Location of Longitudinal Specimens
For 1-1/2" x 2-1/2" Bar

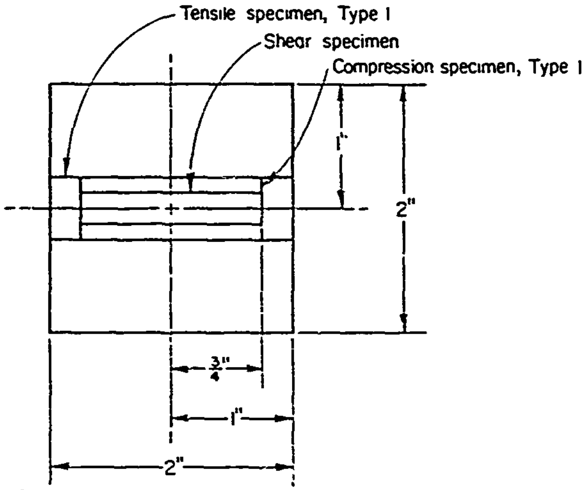


Figure 11. Location of Long Transverse Specimens
For 2" x 2" Bar

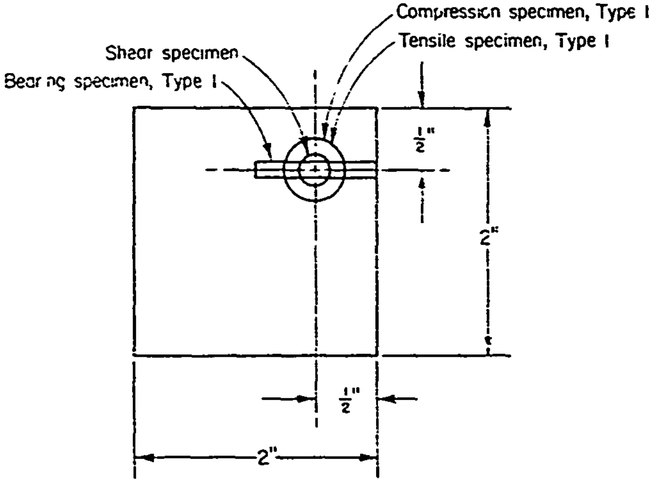


Figure 12. Location of Longitudinal Specimens
For 2" x 2" Bar

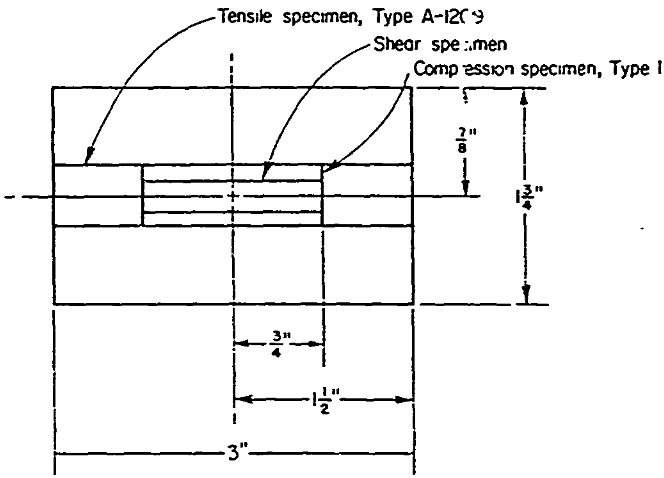


Figure 13. Location of Long Transverse Specimens
For 1-3/4' x 3" Bar

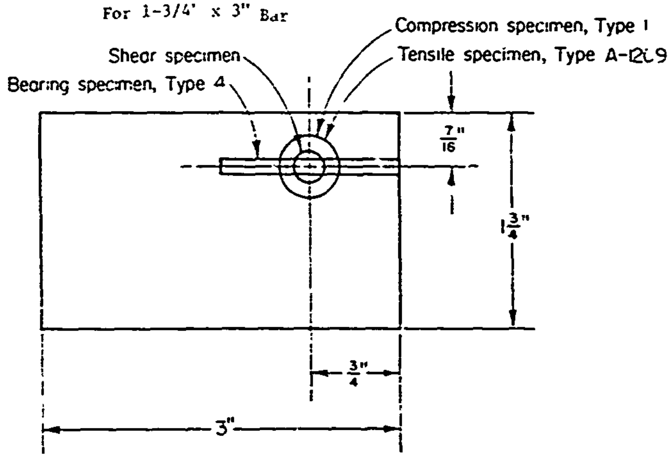


Figure 14. Location of Longitudinal Specimens
For 1-3/4" x 3" Bar

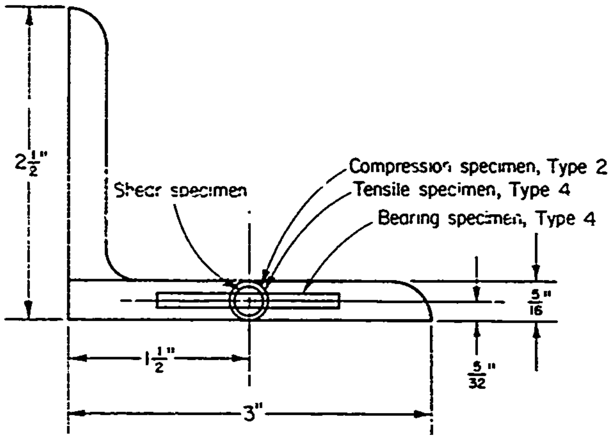


Figure 15. Location of Longitudinal Specimens For Angle

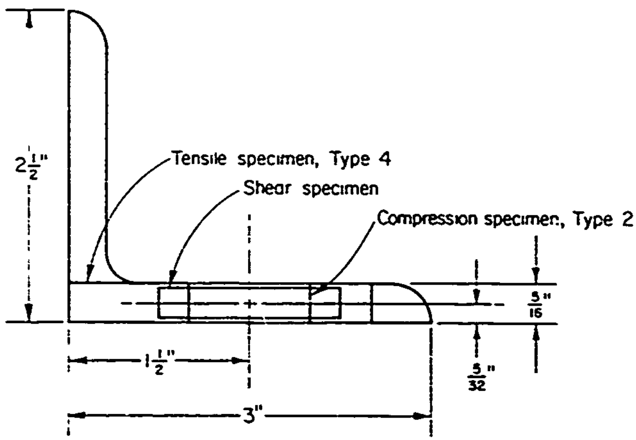


Figure 16. Location of Long Transverse Specimens For Angle

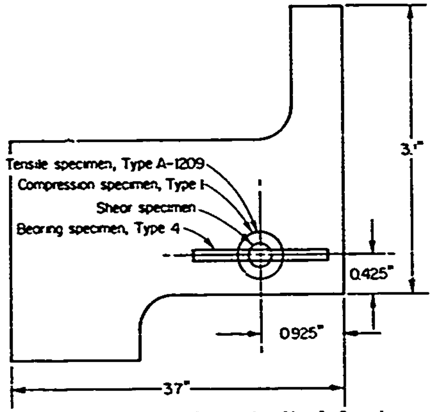


Figure 17. Location of Longitudinal Specimens For Zee

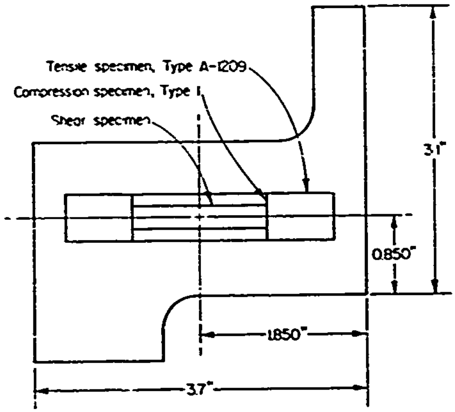


Figure 18. Location of Long Transverse Specimens For Zee

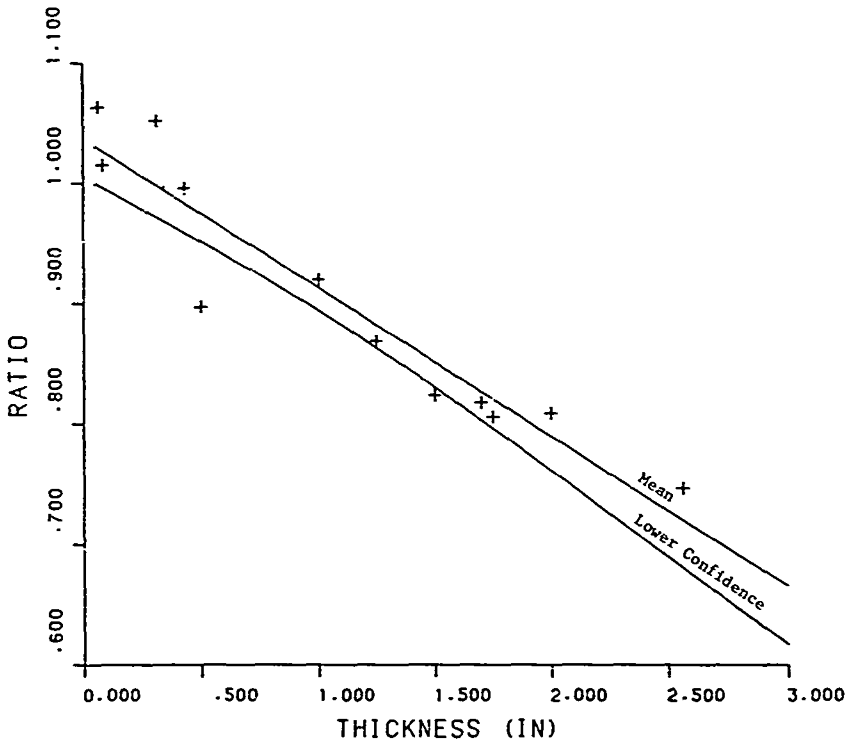


Figure 19. Plot of TUS (LT)/TUS (L) Ratios

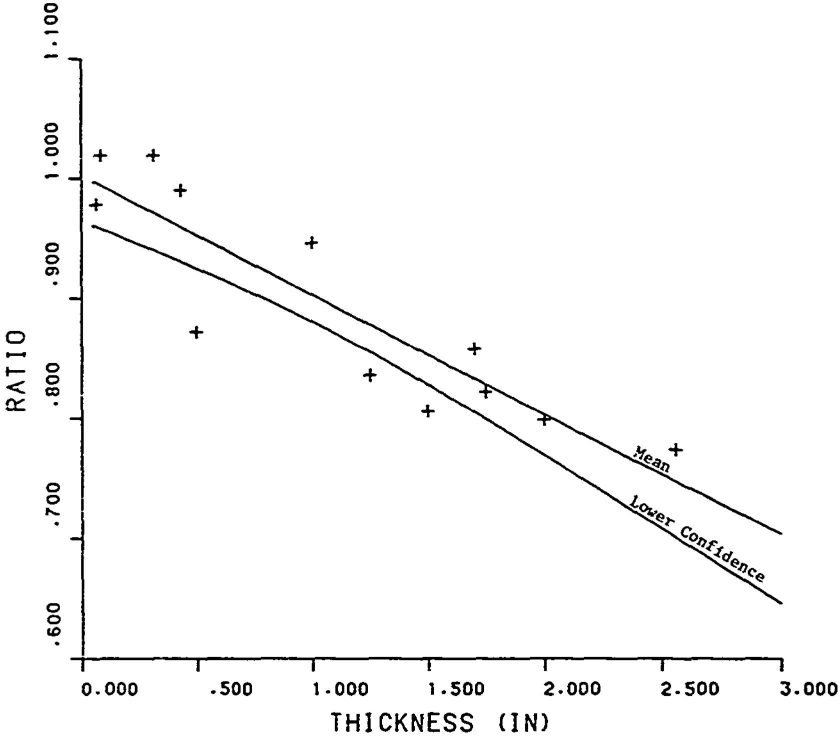


Figure 20. Plot of TYS (LT)/TYS (L) Ratios

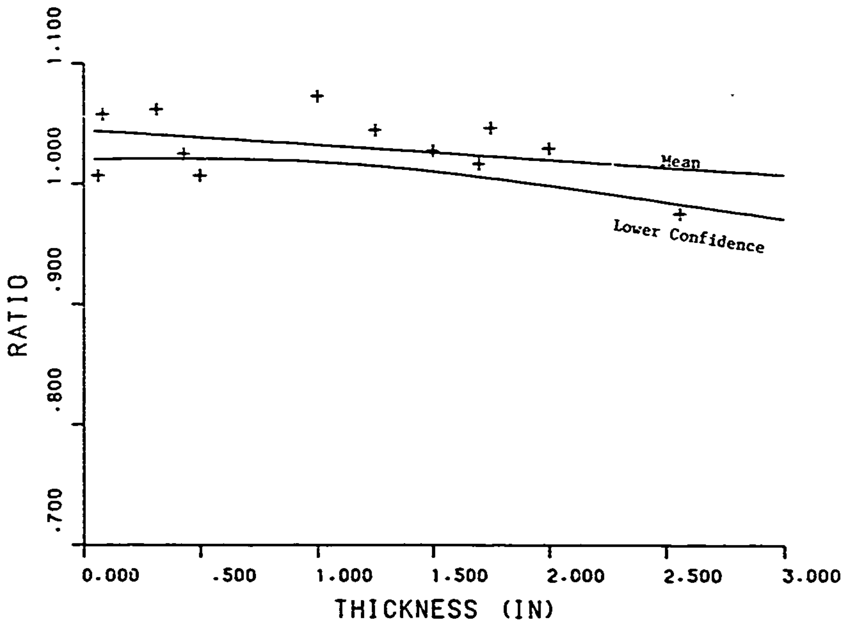


Figure 21. Plot of CYS (L)/TYS (L) Ratios

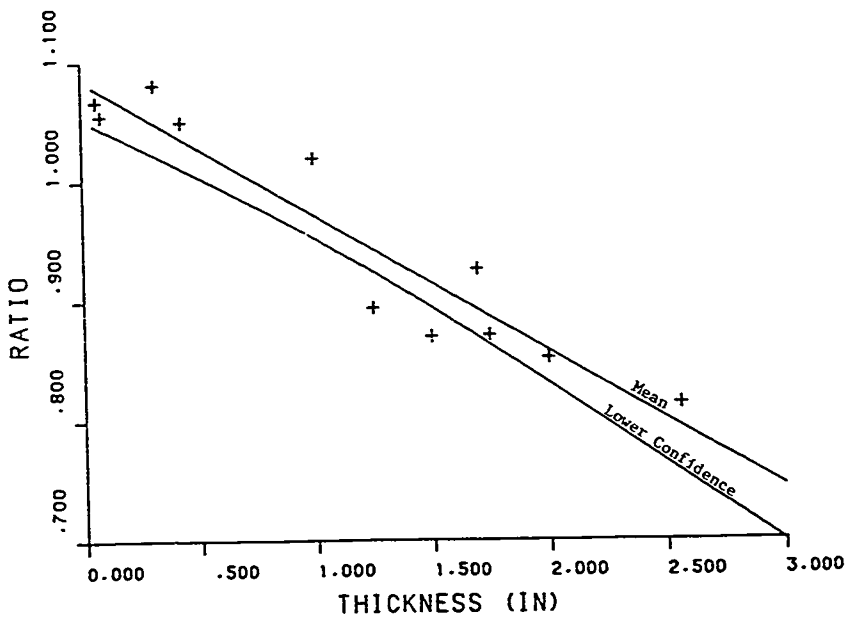


Figure 22. Plot of CYS (LT)/TYS (L) Ratios

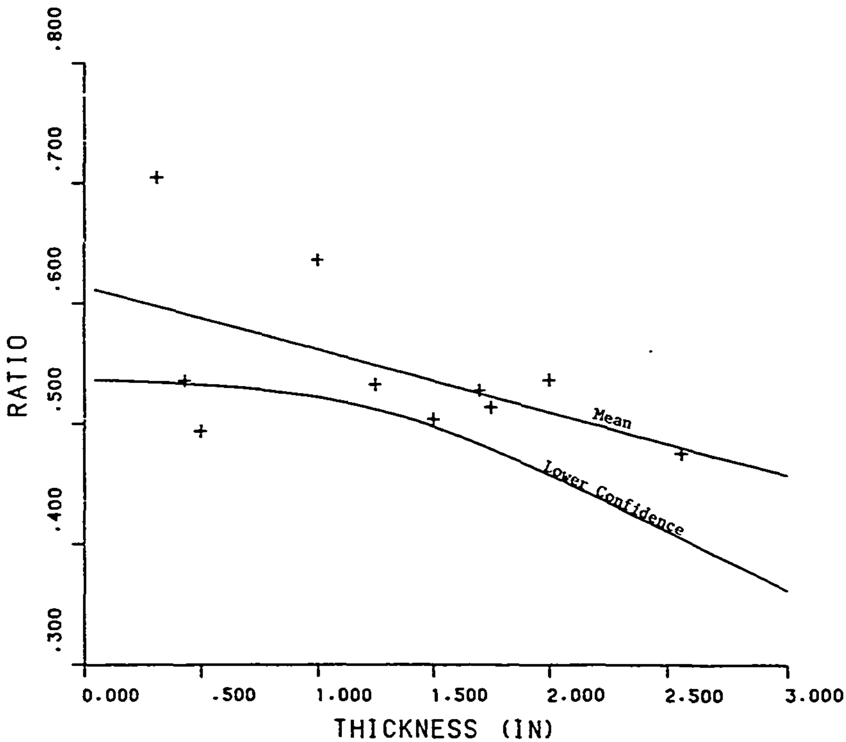


Figure 23. Plot of SUS (L)/TUS (L) Ratios

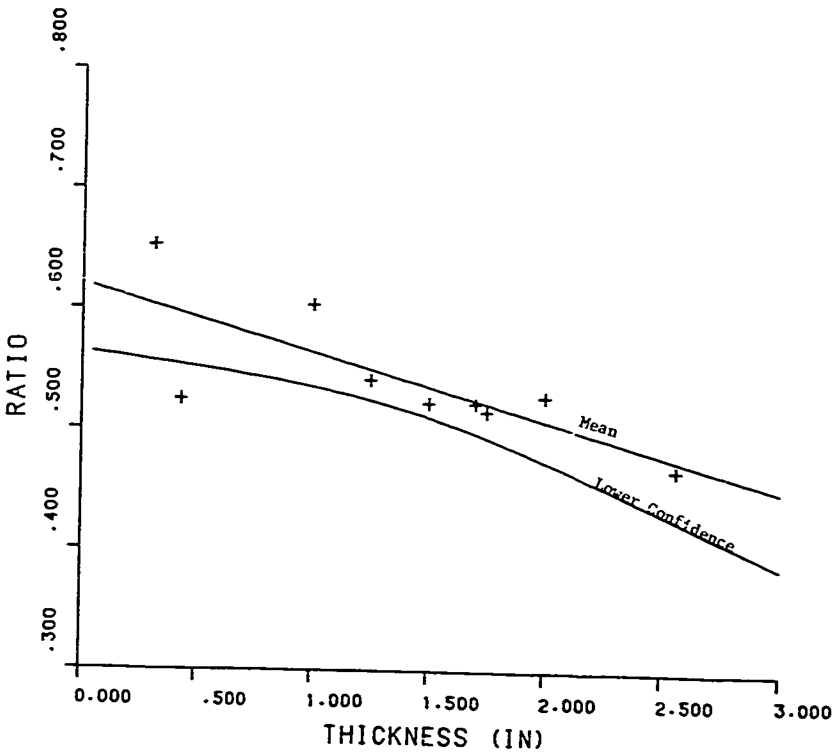


Figure 24. Plot of SUS (LT)/TUS (L) Ratios

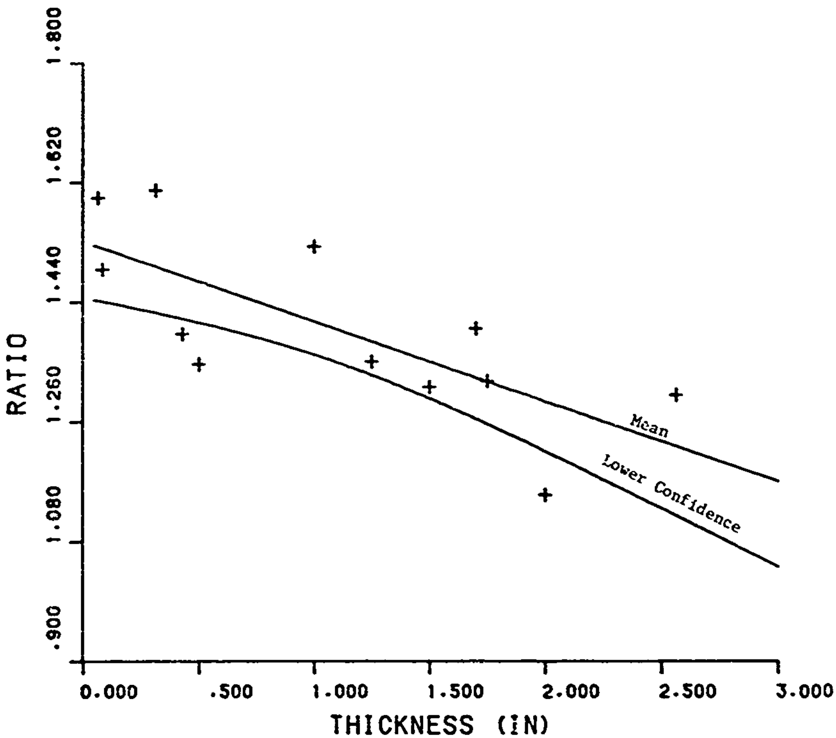


Figure 25. Plot of BUS (L)/TUS (L), e/d = 1.5, Ratios

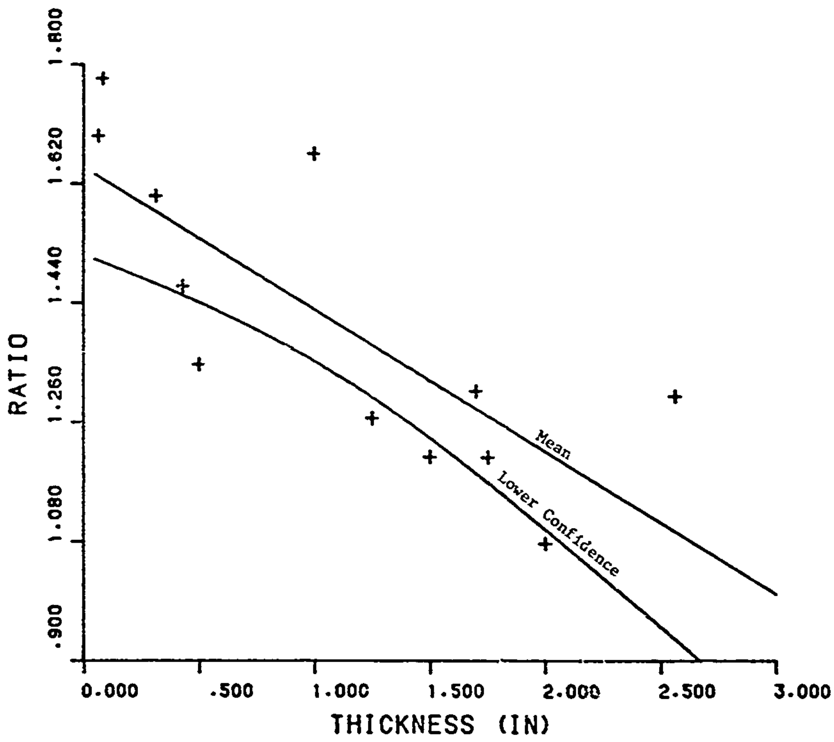


Figure 26. Plot of BYS (L)/TYS (L), e/D = 1.5, Ratios

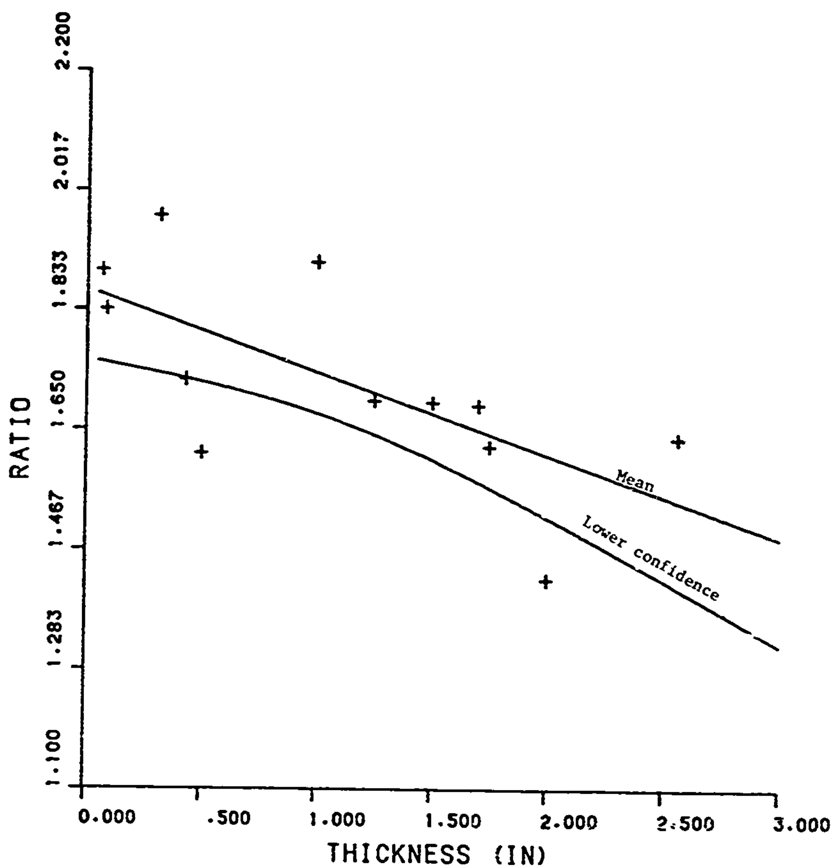


Figure 27. Plo. of BUS (L)/TUS (L), e/D = 2.0, Ratios

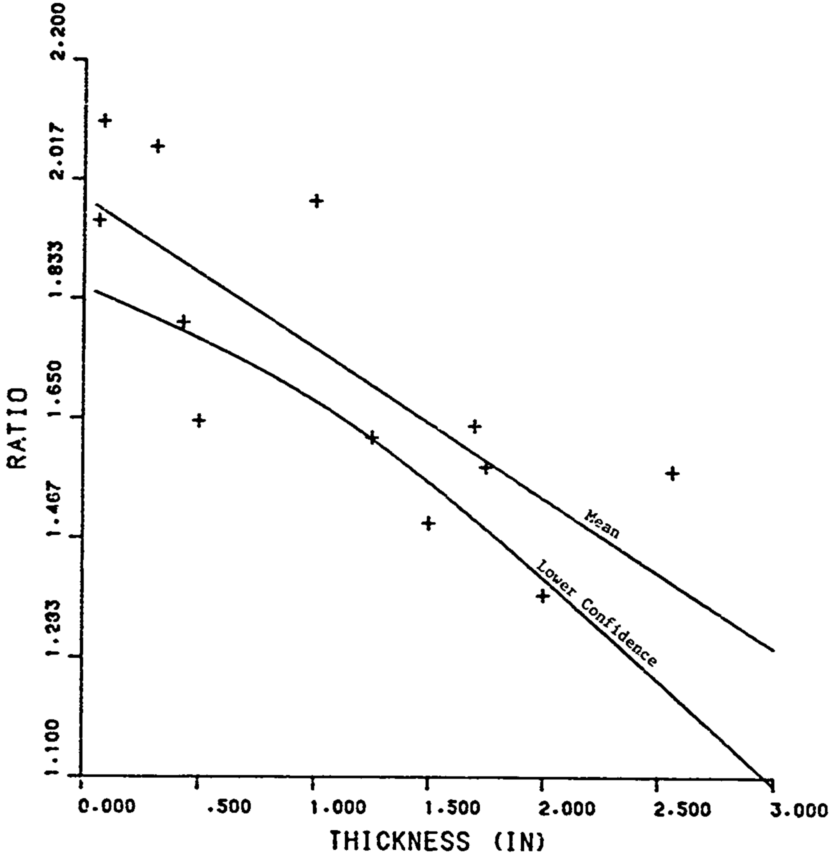


Figure 28. Plot of BYS (L)/TYS (L), e/D = 2.0, Ratios

Ti-6Al-2Sn-4Zr-2Mo Titanium Alloy Sheet

Background

MIL-HDBK-5 currently contains in Table 5.3.3.0(b) A and B values for tensile yield and ultimate strengths for Ti-6Al-2Sn-4Zr-2Mo duplex annealed sheet, but does not have compression, shear, and bearing data. This material is being considered for use in several advanced aircraft and missiles in elevated temperature applications. Consequently, it was desirable to establish the missing design properties for this material.

A literature search revealed that room and elevated temperature tensile, compression, shear, and bearing data for Ti-6Al-2Sn-4Zr-2Mo duplex annealed sheet were available in reference (2). Since the data contained in this reference were insufficient to meet the MIL-HDBK-5 guideline requirements, it was necessary to conduct a test program to resolve this matter.

Test Plan. As defined in Chapter 1, Section 1.4.3 of MIL-HDBK-5, derived values are these room temperature mechanical property values that are established through their relationship to directly calculated (or specification) values for room temperature F_{tu} and F_{ty}. The guidelines for the presentation of data are described in Chapter 9, Section 9.2.9.1, of MIL-HDBK-5 and require at least ten pairs of measurements, each representing a single lot of material. Table 1 shows the test plan to acquire the necessary data. Although data were available from reference (2) for one lot of material, it was decided to procure ten lots of material because the test material in reference (2) had been produced over 14 years ago and the silicon content was not known. MIL-HDBK-5 contains elevated temperature tensile yield and ultimate strength data. It was decided to perform testing so that elevated temperature compression yield and shear ultimate strength data could be included in MIL-HDBK-5. The test plan was designed so as to utilize test material which could be procured immediately.

Material. Rockwell International Corporation, Military Aircraft Division (Columbus, Ohio) supplied at no cost five lots of material in 0.071, 0.080, 0.090, 0.100, and 0.125-inch thicknesses. This material had been produced by RMI to a Rockwell specification, which was equivalent to MIL-T-9046 except requiring a silicon content of 0.06-0.10 percent. Five additional sheet thicknesses; 0.030, 0.040, 0.050, 0.055 and 0.062, were procured from TIMET to MIL-T-9046, Type III, Comp. 6, except silicon content was specified as 0.06-0.10 percent. Each sheet thickness constituted a different heat except for 0.055 and 0.063-inch thicknesses which were from the same heat.

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(2) Dotson, C.L., "Mechanical and T[illegible]roperties of High-Temperature Titanium Alloys", Sou[illegible] [illegible]stitute, AFML-TR-67-41 (April 1967), (MCIC 68426).

The material was supplied in the duplex annealed condition. This thermal treatment consisted of 1650 F for 1/2-hour, air cool, 1450 F for 1-4/hour and air cool.

Test Specimens. Triplicate tests were used as shown in Table 12. The configurations of the test specimens are shown in Figures 29 through 32. The location of the test specimens on the sheet is depicted in Figures 33 through 37.

Testing. All specimens were tested in the "as received" duplex annealed condition in accordance with the procedures described in Appendix A. The results of the mechanical property tests are shown in Table 13. All lots conformed to the minimum tensile properties specified in MIL-T-9046.

Great difficulty was experienced with the shear testing. All of planned shear specimens had long transverse grain orientation. The first specimen tested was AT1 (0.030-inch) thick. Severe deformation occurred around test holes (see Figure 31 for specimen configuration) and examination of fracture surfaces revealed that the fracture was not totally by shear. A thicker specimen, GT1 (0.080-inch thick) was tested next to determine if the problem would prevail in thicker specimens. Again, severe deformation in test area was observed with circuitous cracks between the test holes. To further determine whether thickness of specimen was a factor, specimen JT1 (0.125-inch thick) was tested with similar results.

There are no published specifications for shear testing and test specimen configuration. The shear specimen configuration shown in Figure 3 has been used successfully for a large number of different metallic materials over an extended period of time. Problems in obtaining a shear failure have only been encountered in the past with materials with a very low yield strength (30-50 Ksi). Reducing the width between the test holes has been effective in the past in producing shear failures in low yield strength materials.

Consequently, the width between the test holes on specimen GT2 (0.080-inch thick) was reduced from 0.190 to 0.150-inch by machining, but this change did not produce a shear failure. The same procedure was used on specimen JT2 (0.125-inch thick) without success. The width between the test holes on specimen HT1 (0.090-inch thick) was reduced to 0.100-inch; on specimens ET1 (0.063-inch thick) and GT3 (0.080-inch thick), the test width was reduced to 0.075-inch, but none of these modifications produced a shear failure.

It was thought that possibly shear failures could be obtained with longitudinal specimens. Longitudinal specimens were machined from 0.100-inch thick sheet with test widths of 0.124 and 0.248-inch and tested without success. On the third specimen, the original 0.190-inch test width was reduced to 0.120-inch using a jeweler's saw with 0.006-inch diameter blade in an effort to increase

the stress concentration at the test section. This was unsuccessful. On the fourth longitudinal specimen, the 0.190-inch test width was reduced to 0.100-inch by electrical discharge machining (0.014-inch wide slot). Since this technique did not produce a shear failure, shear testing was discontinued.

<u>Analysis</u>. As previously indicated, derived values refer to those room temperature mechanical property values that are established through their relationships to directly calculated (or specification) values for room temperature F_{tu} and F_{ty}. The procedure is applicable to F_{cy}, F_{su}, F_{bru}, and F_{bry} and involves the pairing of SUS and BUS measurements with TUS measurements for which F_{tu} has been established. Likewise, CYS and BYS measurements are paired with TYS measurements for which F_{ty} has been established. Tensile properties in grain directions not covered by specification are also derived in a similar manner.

Using the above relationships, reduced ratios for the various "unknown" properties were determined using the computational procedure described in Chapter 9, Section 9.2.9.2 of MIL-HDBK-5. The primary test direction for sheet is long transverse. Consequently, the lot average test values for longitudinal and long transverse compression yield and long transverse bearing yield strength were paired with the corresponding lot average test values for long transverse tensile yield strength. Similarly, the long transverse bearing ultimate values were paired to the corresponding long transverse tensile ultimate values. Reduced ratios were computed using the following equation when the ratios did not vary with thickness:

$$R = \bar{r} - \frac{t_{0.95}s}{\sqrt{n}} \quad ,$$

where R = reduced ratio

$\bar{r}$ = average of n ratios

s = standard deviation of the ratios

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-1 degrees of freedom

n = number of ratios.

When the ratio varied with thickness, the following equation was used for regression analysis:

$$R = \bar{r}' - t_{0.95}s'\sqrt{\frac{1}{n} + \frac{\left(x_o - \Sigma x/n\right)^2}{\left(\Sigma x^2\right) - \left(\Sigma x\right)^2/n}} \quad ,$$

where R = reduced ratio

$\overline{r}'$ = mean ratio for specific thickness, x_o

s' = standard error of estimate

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-2 degrees of freedom

n = number of ratios

x_o = specific thickness

x = individual thickness values for ratios.

A computer program was used to perform the analyses. The results are shown in Tables 14 through 16.

Only the $\frac{BUS}{TUS}$ ratios showed regression (positive) with increasing thickness as shown in Table 16, and Figures 38 and 39. Because of this regression for the $\frac{BUS}{TUS}$ ratios, it was decided to present design values for four thickness ranges for sheet. A summary of the computed reduced ratios is presented in Table 17.

MIL-HDBK-5 Table 5.3.3.0(b) does not contain a compression modulus value for Ti-6Al-2Sn-4Zr-2Mo sheet. Consequently, an E_c value was determined by using the same ratio technique. This computed average ratio for $\frac{E_c}{E}$ is shown in Table 18. Since moduli are presented as typical values, not minimum, the average ratio was used to compute E_c value.

The same equation (not regression) that was used to compute a lower confidence interval (reduced ratio) for compression yield and bearing yield strengths was utilized to compute the lower confidence intervals at each test temperature for compression yield strength. The results of these computations are shown in Table 19.

The effect of temperature on compressive modulus was established by the computations in Table 20. Since the elevated temperature moduli curves in MIL-HDBK-5 are typical, not minimum, the average percentage of room temperature value at each temperature was used.

The reduced ratios in Tables 17 and 18 were used to compute design values in revised Table 5.3.3.0(b) (Table 21) for compression and bearing strength as well as compression modulus value. The compression yield strength lower confidence interval at each temperature was used to construct elevated temperature working curve in Figure 40. The corresponding MIL-HDBK-5 illustration is shown in Figure 41. The elevated temperature compression modulus curve was determined using average percentages shown in Table 20. These percentages were plotted on the existing MIL-HDBK-5 Figure 5.3.3.1.4 for comparison with the elevated temperature tensile modulus curve as depicted in Figure 42. The elevated temperature percentages for compression modulus compared closely with those for tensile modulus. Consequently, the caption for the existing Figure 5.3.3.1.4 has been changed as shown in Figure 43.

TABLE 12. TEST PLAN FOR TI-6AL-2SN-4ZR-2MO SHEET

Sheet Thickness	Grain Direction	Room Temperature: Tensile	Room Temperature: Compression	Room Temperature: Shear	Room Temperature: Bearing e/D=1.5	Room Temperature: Bearing e/d=2.0	Elevated Temperature, 400 F, 600 F, 800 F, 1000 F: Compression	Elevated Temperature, 400 F, 600 F, 800 F, 1000 F: Shear
0.030	L		3					
	LT	3	3	3	3	3		
0.040	L		3					
	LT	3	3	3	3	3		
0.050	L		3					
	LT	3	3	3	3	3	3	3
0.055	L		3					
	LT	3	3	3	3	3		
0.063	L		3					
	LT	3	3	3	3	3		
0.071	L		3					
	LT	3	3	3	3	3		
0.080	L		3					
	LT	3	3	3	3	3	3	3
0.090	L		3					
	LT	3	3	3	3	3		
0.100	L		3					
	LT	3	3	3	3	3		
0.125	L		3					
	LT	3	3	3	3	3	3	3
0.040*	L	X	X	X	X	X	X	X
	LT	X	X	X	X	X	X	X

*Data available in reference (2).

TABLE 13. MECHANICAL PROPERTIES OF TI-6AL-2SN-4ZR-2MO SHEET

Heat Number	Thickness, Inches	Temperature F	Grain Direction	Specimen Identification	Tension TUS, ksi	Tension TYS, ksi	Tension e, percent in 2 in.	Tension E, 10^3 ksi	Compression CYS, ksi	Compression E_c, 10^3 ksi	Bearing e/D=1.5 BUS, ksi	Bearing e/D=1.5 BYS, ksi	Bearing 2/D=2.0 BUS, ksi	Bearing 2/D=2.0 BYS, ksi
N-9882	0.030	RT	L	AL1					158.1	19.0				
				AL2					158.3	18.9				
				AL3					158.8	19.1				
				Average					158.4	19.0				
			LT	AT1	153.3	143.1	14.0	16.6	154.9	18.5	217.1	195.4	245.1	229.8
				AT2	150.5	143.8	13.0	16.5	153.3	18.8	234.2	204.1	243.0	226.2
				AT3	151.3	143.2	12.5	18.3	154.9	18.5	202.2	193.0	240.4	197.3
				Average	151.7	143.4	13.2	17.1	154.4	18.6	217.8	197.5	242.8	217.8
N-6112	0.040	RT	L	BL1					162.5	19.4				
				BL2					160.5	19.2				
				BL3					160.6	19.2				
				Average					161.2	19.3				
			LT	BT1	149.3	140.7	14.0	17.4	148.7	18.2	232.9	193.9	281.2	261.3
				BT2	148.4	138.1	12.5	17.5	150.1	18.2	230.6	191.3	261.7	235.6
				BT3	149.6	141.5	12.0	17.0	150.4	18.3	229.8	192.3	248.0	217.9
				Average	149.1	140.1	12.8	17.3	149.7	18.2	231.1	192.5	263.7	238.3
P-2309	0.050	RT	L	CL1					155.9	19.1				
				CL2					156.4	19.2				
				CL3					156.7	19.2				
				Average					156.3	19.2				
			LT	CT1	151.4	142.1	15.0	16.5	154.0	18.6	241.7	199.3	298.0	230.0
				CT2	151.1	142.2	16.0	16.4	152.3	18.4	233.2	195.0	297.1	220.2
				CT3	151.3	142.2	17.5	16.2	152.7	18.5	234.0	196.0	294.4	235.4
				Average	151.3	142.2	16.2	16.4	153.0	18.5	236.3	196.8	296.5	231.2
		400	LT	CT4					117.8	17.7				
				CT5					118.4	18.0				
				CT6					116.7	17.7				
				Average					117.6	17.8				
		600	LT	CT7					103.6	16.7				
				CT8					102.5	16.9				
				CT9					102.9	16.4				
				Average					103.0	16.7				

TABLE 13. CONTINUED

Heat Number	Thickness, inches	Temperature, F	Grain Direction	Specimen Identification	Tension TUS, ksi	Tension TYS, ksi	Tension e, percent in 2 in.	Tension E, 10^3 ksi	Compression CYS, ksi	Compression E_c, 10^3 ksi	Bearing e/D=1.5 BUS, ksi	Bearing e/D=1.5 BYS, ksi	Bearing 2/D=2.0 BUS, ksi	Bearing 2/D=2.0 BYS, ksi
P-2309	0.050	800	LT	CT10					98.6	15.6				
				CT11					98.4	15.8				
				CT12					98.1	15.7				
				Average					98.4	15.7				
		1000	LT	CT13					88.9	14.6				
				CT14					88.8	14.8				
				CT15					88.9	15.0				
				Average					88.9	14.8				
P-4426	0.055	RT	L	DL1					144.0	18.1				
				DL2					144.6	18.1				
				DL3					144.3	18.0				
				Average					144.3	18.1				
			LT	DT1	149.7	142.4	14.5	17.1	160.0	19.4	236.2	194.0	274.2	236.6
				DT2	150.4	141.0	14.0	17.9	160.6	19.4	234.4	190.5	288.1	244.3
				DT3	148.4	141.8	13.5	17.5	160.7	19.5	234.1	190.2	290.8	238.0
				Average	149.5	141.7	14.0	17.5	160.4	19.4	234.9	191.6	284.4	239.6
P-4426	0.063	RT	L	FL1					145.4	18.2				
				FL2					141.5	18.3				
				FL3					146.5	18.3				
				Average					146.1	18.3				
			LT	FT1	148.3	142.4	15.0	17.9	156.3	19.3	237.0	196.3	294.8	237.8
				FT2	148.9	142.4	14.0	17.3	156.7	19.3	237.8	195.5	297.3	239.8
				FT3	149.1	142.8	15.0	16.7	157.4	19.2	234.9	194.5	293.8	241.9
				Average	148.8	142.5	14.7	17.3	156.8	19.3	236.6	195.4	295.3	239.8
800707-03-2	0.071	RT	L	FL1					154.7	18.5				
				FL2					155.3	18.3				
				FL3					155.2	18.4				
				Average					155.1	18.4				
			LT	FT1	145.7	143.3	16.0	15.5	148.6	17.6	226.5	189.7	292.5	233.2
				FT2	146.0	143.0	17.5	15.8	149.0	17.6	229.4	192.0	294.2	230.2
				FT3	146.7	143.8	16.5	16.2	148.6	17.6	230.8	193.4	295.2	232.0
				Average	146.1	143.4	16.7	15.8	148.7	17.6	228.9	191.7	294.0	231.8

TABLE 13. CONTINUED

Heat Number	Thickness, Inches	Temperature F	Grain Direction	Specimen Identification	Tension				Compression		Bearing			
											e/D=1.5		2/D=2.0	
					TUS, ksi	TYS, ksi	e, percent in 2 in.	E, 10^3 ksi	CYS, ksi	E, 10^3 ksi	BUS, ksi	BYS, ksi	BUS, ksi	BYS, ksi
890423-13-5	0.080	RT	L	GL1					159.1	18.4				
				GL2					159.5	18.7				
				GL3					160.3	18.7				
				Average					159.6	18.6				
			LT	GT1	151.4	145.6	17.0	16.7	154.6	18.0	238.6	200.9	305.9	235.4
				GT2	150.?	145.8	16.5	16.8	153.6	18.0	237.8	200.9	304.1	237.2
				GT3	150.1	144.8	15.5	16.1	154.6	18.1	237.0	200.4	306.3	232.0
				Average	150.6	145.4	16.3	16.4	154.3	18.0	237.8	200.7	305.4	234.9
		400	LT	GT4					115.2	16.8				
				GT5					115.5	17.0				
				GT6					116.0	17.0				
				Average					115.6	16.9				
		600	LT	GT7					103.6	16.0				
				GT8					104.3	15.9				
				GT9					104.2	15.8				
				Average					104.0	15.9				
		800	LT	GT10					97.9	14.9				
				GT11					97.8	14.7				
				GT12					97.9	15.0				
				Average					97.9	14.9				
		1000	LT	GT13					85.0	13.0				
				GT14					85.0	13.1				
				GT15					85.5	13.0				
				Average					85.2	13.0				
890462-04-4	0.090	RT	L	HL1					155.0	18.5				
				HL2					154.7	18.5				
				HL3					-	-				
				Average					154.8	18.5				
			LT	HT1	146.3	142.9	14.0	17.2	153.7	18.5	242.9	198.8	305.4	233.6
				HT2	146.9	142.9	15.5	16.9	153.4	18.6	243.7	202.0	308.3	227.7
				HT3	145.0	141.9	12.5	17.3	154.5	18.7	240.5	199.9	307.3	237.0
				Average	146.1	142.6	14.0	17.1	153.9	18.6	242.4	200.2	307.0	232.8

TABLE 13. CONCLUDED

Heat Number	Thickness, Inches	Temperature F	Grain Direction	Specimen Identification	Tension TUS, ksi	Tension TYS, ksi	Tension e, percent in 2 in.	Tension E, 10^3ksi	Compression CYS, ksi	Compression E, 10^3ksi	Bearing e/D=1.5 BUS, ksi	Bearing e/D=1.5 BYS, ksi	Bearing e/D=2.0 BUS, ksi	Bearing e/D=2.0 BYS, ksi
80070-10-1	0.100	RT	L	IL1					154.3	19.2				
				IL2					152.3	19.2				
				IL3					152.9	19.3				
				Average					153.2	19.2				
			LT	IT1	145.8	140.8	13.5	17.7	150.0	18.7	238.6	199.5	300.6	235.1
				IT2	145.6	140.1	15.0	17.1	151.2	18.7	238.1	195.5	299.6	235.1
				IT3	146.0	140.3	14.0	17.1	151.5	18.8	240.5	197.8	299.6	239.3
				Average	145.8	140.4	14.2	17.3	150.9	18.7	239.1	197.6	299.9	236.5
800786 09-1	0.125	RT	L	JL1					151.9	18.7				
				JL2					152.2	18.9				
				JL3					152.8	19.0				
				Average					152.3	18.9				
			LT	JT1	145.6	142.3	16.0	18.5	149.9	18.4	238.6	197.2	299.8	239.8
				JT2	145.8	141.3	14.5	17.1	150.7	18.6	239.4	200.3	300.6	240.6
				JT3	146.1	141.9	15.0	17.8	150.6	18.6	-	201.1	302.9	238.2
				Average	145.8	141.8	15.2	17.8	150.4	18.5	239.0	199.5	301.1	239.5
		400	LT	JT4					113.9	17.2				
				JT5					113.6	17.2				
				JT6					113.9	17.2				
				Average					113.8	17.2				
		600	LT	JT7					101.4	16.4				
				JT8					101.2	16.2				
				JT9					100.9	16.1				
				Average					101.2	16.2				
		800	LT	JT10					95.5	15.1				
				JT11					95.1	14.8				
				JT12					95.1	15.6				
				Average					95.2	15.2				
		1000	LT	JT13					81.9	13.4				
				JT14					81.3	13.8				
				JT15					81.0	14.1				
				Average					81.4	13.8				

TABLE 14. LIST OF RATIOS VERSUS THICKNESS FOR TI-6AL-2SN-4ZR-2MO

	CYS(L)/TYS(LT)	CYS(LT)/TYS(LT)	THICKNESS
1	1.105	1.077	.030
2	1.151	1.069	.040 (from ref. (2))
3	1.075	1.038	.040
4	1.099	1.076	.050
5	1.018	1.132	.055
6	1.025	1.100	.063
7	1.082	1.037	.071
8	1.098	1.061	.080
9	1.086	1.079	.090
10	1.091	1.075	.100
11	1.074	1.061	.125

TABLE 14. CONTINUED

STATISTICS FOR THE PLOT OF CYS(L)/TYS(LT)
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.0957 -.1998 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .0366

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0381

R-SQUARED STATISTIC= -8.31

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.0402 AND 1.1512
AND ON B(2) ARE -.9597 AND .5601

SIGNIFICANT REGRESSION NO

MEAN RATIO= 1.082

REVISED T STATISTIC= 1.812

REDUCED RATIO= 1.062

TABLE 14. CONCLUDED

STATISTICS FOR THE PLOT OF CYS(LT)/TYS(LT)
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.0792 -.0695 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .0266

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0280

R-SQUARED STATISTIC= *****

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.0385 AND 1.1200
AND ON B(2) ARE -.6473 AND .4683

SIGNIFICANT REGRESSION NO

MEAN RATIO= 1.073

REVISED T STATISTIC= 1.812

REDUCED RATIO= 1.059

TABLE 15. LIST OF RATIOS VERSUS THICKNESS FOR TI-6AL-2SN-4ZR-2MO

	BYS(LT)/TYS(LT)1.5	BYS(LT)/TYS(LT)2.0	THICKNESS	
1	1.377	1.519	.030	
2	1.374	1.701	.040	(from ref (2))
3	1.428	1.[illegible]	.040	
4	1.384	1.[illegible]	.050	
5	1.352	1.[illegible]	.055	
6	1.371	[illegible]3	.063	
7	1.337	1.616	.071	
8	1.380	1.616	.080	
9	1.404	1.633	.090	
10	1.407	1.684	.100	
11	1.407	1.689	.125	

TABLE 15. CONTINUED

STATISTICS FOR THE PLOT OF BYS(LT)/TYS(LT)15
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.3670 - .2479 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .0264

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0266

R-SQUARED STATISTIC= -2.83

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.3279 AND 1.4060
AND ON B(2) ARE -.2659 AND .7817

SIGNIFICANT REGRESSION NO

MEAN RATIO= 1.384

REVISED T STATISTIC= 1.812

REDUCED RATIO= 1.369

TABLE 15. CONCLUDED

STATISTICS FOR THE PLOT OF BYS(LT)/TYS(LT)2.0
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.6183 + .4853 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .0562

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0574

R-SQUARED STATISTIC= -4.04

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.5347 AND 1.7020
AND ON B(2) ARE -.6561 AND 1.6327

SIGNIFICANT REGRESSION NO

MEAN RATIO= 1.651

REVISED T STATISTIC= 1.812

REDUCED RATIO= 1.621

TABLE 16. LIST OF RATIOS VERSUS THICKNESS FOR TI-6AL-2SN-4ZR-2MO

	BUS(LT)/TUS(LT)1.5	BUS(LT)/TUS(LT)2.0	THICKNESS	
1	1.436	1.601	.030	
2	1.550	1.769	.040	(from ref (2))
3	1.607	1.993	.040	
4	1.562	1.960	.050	
5	1.571	1.902	.055	
6	1.590	1.965	.063	
7	1.567	2.012	.071	
8	1.579	2.028	.080	
9	1.659	2.101	.090	
10	1.640	2.057	.100	
11	1.639	2.065	.125	

TABLE 16. CONTINUED

STATISTICS FOR THE PLOT OF BUS(LT)/TUS(LT)15
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.4782 + 1.5316 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .0603

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .0429

R-SQUARED STATISTIC= 49.44

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.4157 AND 1.5407
AND ON B(2) ARE .6764 AND 2.3868

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.012	1.496	1.443
.024	1.514	1.470
.035	1.532	1.496
.047	1.550	1.521
.059	1.568	1.543
.070	1.586	1.562
.082	1.604	1.577
.094	1.522	1.589
.106	1.540	1.600
.118	1.658	1.609
.129	1.676	1.618
.141	1.594	1.627
.153	1.712	1.636
.165	1.730	1.544
.176	1.748	1.652
.188	1.766	1.661

TABLE 16. CONCLUDED

STATISTICS FOR THE PLOT OF BUS(LT)/TUS(LT)2.0
VERSUS THICKNESS FOR
TI-6AL-2SN-4ZR-2MO

REGRESSED LINE IS
Y = 1.6970 + 3.7715 X (THICKNESS)

NUMBER OF DATA= 11

STANDARD DEVIATION OF Y = .1474

STANDARD ERROR OF ESTIMATE
(OR EFFECTIVE SCATTER ABOUT THE LINE)= .1040

R-SQUARED STATISTIC= 50.24

95 PERCENT T FACTOR= 1.833

95 PERCENT CONF.
LIMITS ON B(1) ARE 1.5453 AND 1.8487
AND ON B(2) ARE 1.6962 AND 5.8469

SIGNIFICANT REGRESSION YES

MEAN AND REDUCED RATIO FOR SELECTED THICKNESSES

THICKNESS	MEAN RATIO	REDUCED RATIO
.012	1.741	1.612
.024	1.785	1.677
.035	1.830	1.742
.047	1.874	1.803
.059	1.919	1.858
.070	1.963	1.905
.082	2.007	1.942
.094	2.052	1.972
.106	2.096	1.998
.118	2.140	2.022
.129	2.184	2.044
.141	2.229	2.066
.153	2.273	2.087
.165	2.317	2.108
.176	2.362	2.129
.188	2.406	2.150

TABLE 17. REDUCED RATIOS FOR TI-6AL-2SN-4ZR-2MO SHEET

Ratio	E/D Ratio	Thickness Range, Inches			
		≤0.046	0.047-0.093	0.094-0.140	0.141-0.187
CYS(L)/TYS(LT)		1.062	1.062	1.062	1.062
CYS(LT)/TYS(LT)		1.059	1.059	1.059	1.059
BYS(LT)/TYS(LT)	1.5	1.369	1.369	1.369	1.369
BUS(LT)/TUS(LT)	1.5	1.443	1.521	1.589	1.627
BYS(LT)/TYS(LT)	2.0	1.621	1.621	1.621	1.621
BUS(LT)/TUS(LT)	2.0	1.612	1.803	1.972	2.066

TABLE 18. EC/E RATIOS FOR TI-6AL-2SN-4ZR-2MO SHEET

IDENTIFICATION	RT AVG	$\frac{E_c}{E}$
0.030 IN.HT.NO.N-9862	17.1	108.8
0.040 IN.HT.NO.N-6112	17.3	105.2
0.050 IN.HT.NO.P-2309	16.4	112.8
0.055 IN.HT.NO.P-4426	17.5	110.9
0.063 IN.HT.NO.P-4426	17.3	111.6
0.071 IN.HT.NO.800707-03-2	15.8	111.4
0.080 IN.HT.NO.890423-15-5	16.4	109.8
0.090 IN.HT.NO.890462-04-4	17.1	106.8
0.100 IN.HT.NO. 80070-10-1	17.3	106.1
0.125 IN.HT.NO. 80078-09-1	17.8	103.9
	NUMBER R	10
	AVG R	109.1

TABLE 19. EFFECT OF TEMPERATURE ON COMP YIELD STRENGTH OF TI-6AL-2SN-4ZR-2MO SHT

IDENTIFICATION		RT AVG	400F	600F	800F	1000F
			PERCENT R-T AT INDICATED TEMPERATURE			
0.050 IN.HT.NO.H-9802		153.0	76.9	67.3	64.3	58.1
0.080 IN.HT.NO.890423-15-5		154.3	74.9	67.4	63.4	55.2
0.125 IN.HT.NO.800706-09-1		150.4	75.7	67.3	63.3	54.1
0.040 IN.HT.NO.V-3016	REF(1)	149.6	74.4	66.6	64.5	57.0
0.040 IN.HT.NO.V-3016	REF(1)	144.4	73.3	66.1	60.9	57.0
	NUMBER R		5	5	5	5
	AVG R		75.0	67.0	63.3	56.3
	SUM R		375.2	334.8	316.5	281.5
	SUMSQ R		28159.5	22417.9	20043.3	15853.8
	SDEV R		1.3263	0.5501	1.4198	1.5945
	SDEV RBAR		0.5931	0.2460	0.6350	0.7131
	PERCENT RT		73.6	66.4	61.8	54.6

TABLE 20. EFFECT OF TEMPERATURE ON COMP MODULUS OF TI-6AL-2SN-4ZR-2MO SHEET

IDENTIFICATION	RT AVG	PERCENT R-T AT INDICATED TEMPERATURE 400F	600F	800F	1000F
0.050 IN.HT.NO.N-9882	18.5	96.2	90.3	84.9	80.0
0.060 IN.HT.NO.890423-15-5	18.0	93.9	85.3	82.8	72.2
0.125 IN.HT.NO.800736-09-1	18.5	93.0	87.6	82.2	74.6
0.040 IN.HT.NO.V-3016 REF(1)	14.2	89.4	85.2	79.6	74.6
0.040 IN.HT.NO.V-3016 REF(1)	14.5	86.2	79.3	75.9	70.3
NUMBER R		5	5	5	5
AVG		91.7	86.1	81.0	74.4

TABLE 21. PROPOSED MIL-HDBK-5 TABLE 5.3.3.0(b)

TABLE 5.3.3.0(b). *Design Mechanical and Physical Properties of Ti-6Al-2Sn-4Zr-2Mo*

Specification	MIL-T-9046, Type III, Comp. G										MIL-T-9047		AMS 4976
Form	Sheet and strip										Bars		Forgings
Condition	Duplex annealed								Triplex annealed		Duplex annealed		Duplex annealed
Thickness or diameter, in.	≤ 0.046		0.047–0.093		0.094–0.140		0.141–0.187		≤ 0.187		≤ 2.000[a]		...
Basis	A	B	A	B	A	B	A	B	A	B	A	B	S
Mechanical properties:													
F_{tu}, ksi:													
L	135[b]	143	135[b]	143	135[b]	143	135[b]	143	144	148	130[f]	144	130[e]
LT	135[b]	143	135[b]	143	135[b]	143	135[b]	143	144	148	...	...	...
F_{ty}, ksi:													
L	125[c]	136	125[c]	136	125[c]	136	125[c]	136	135	140	120[f]	131	120[e]
LT	125[c]	134	125[c]	134	125[c]	134	125[c]	134	133	137	...	...	...
F_{cy}, ksi:													
L	132	142	132	142	132	142	132	142	...	...	...	...	...
LT	132	142	132	142	132	142	132	142	...	...	...	...	...
F_{su}, ksi	...	...	...	...	...	...	...	...	...	...	...	...	...
F_{bru}[g], ksi:													
(e/D = 1.5)	195	206	205	217	214	227	219	232	...	...	...	...	...
(e/D = 2.0)	217	230	243	258	266	282	279	295	...	...	...	...	...
F_{bry}[g], ksi:													
(e/D = 1.5)	171	183	171	183	171	183	171	183	...	...	...	...	...
(e/D = 2.0)	202	217	202	217	202	217	202	217	...	...	...	...	...
e, percent (S-basis):													
L	d	...	10	...	10	...	10	...	d	...	10	...	10
LT	d	...	10	...	10	...	10	...	d	...	...	...	...
E, 10^3 ksi	16.5												
E_c, 10^3 ksi	18.0												
G, 10^3 ksi	6.2												
μ	0.32												
Physical properties:													
ω, lb/in.^{3}	0.164												
C, Btu/(lb)(F)	See Figure 5.3.3.0												
K, Btu/[(hr)(ft^2)(F)/ft]	See Figure 5.3.3.0												
α, 10^{-6} in./in./F	See Figure 5.3.3.0												

[a] Maximum of 10 square inches cross-sectional area.
[b] The A values are higher than specification values as follows: F_{tu} (L&LT) = 139 ksi.
[c] The A values are higher than specification values as follows: F_{ty} (L) = 131 ksi, F_{ty} (LT) = 129 ksi.
[d] 8% for < 0.020 in. and 10% for ≥ 0.020 in.
[e] Grain direction not specified
[f] The A values are higher than specification values as follows: F_{tu} (L) = 138 ksi, F_{ty} (L) = 125 ksi.
[g] Bearing values are "dry pin" values per Section 1.4.7.1.

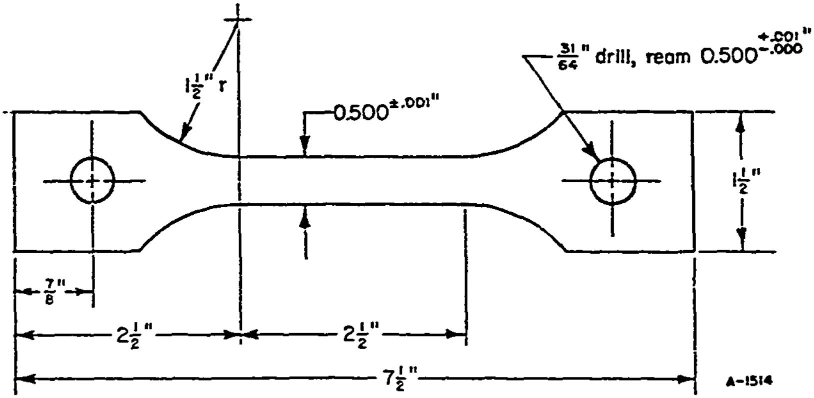

Figure 29. Tensile Specimen

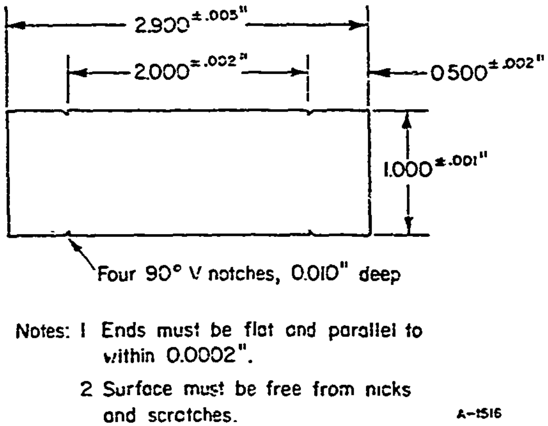

Figure 30. Compression Specimen

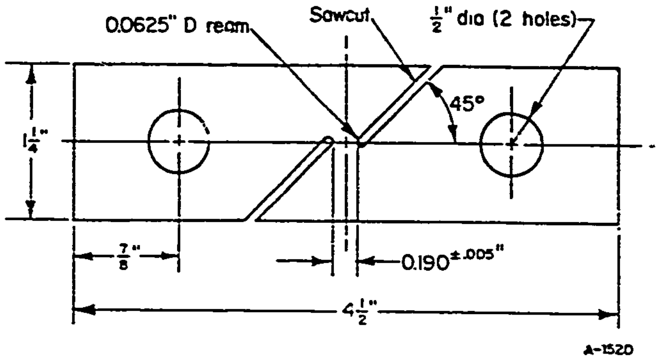

Figure 31. Shear Specimen

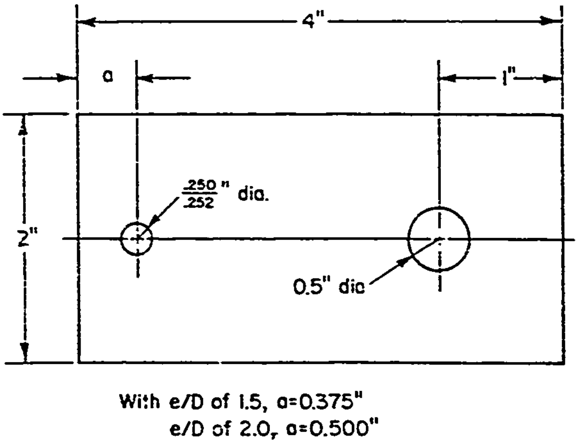

Figure 32. Bearing Specimen

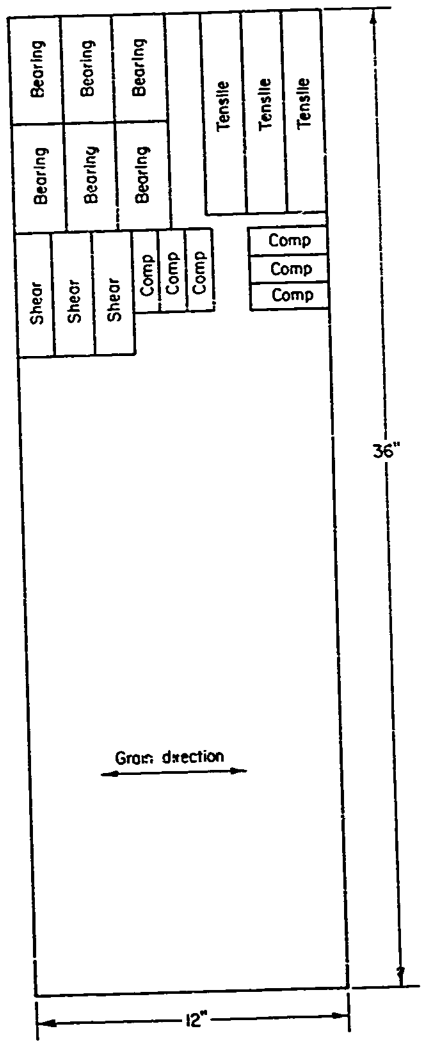

Figure 33. Location of Test Specimens, 0.030, 0.040, 0.055, 0.063, and 0.071-inch Thick Sheet

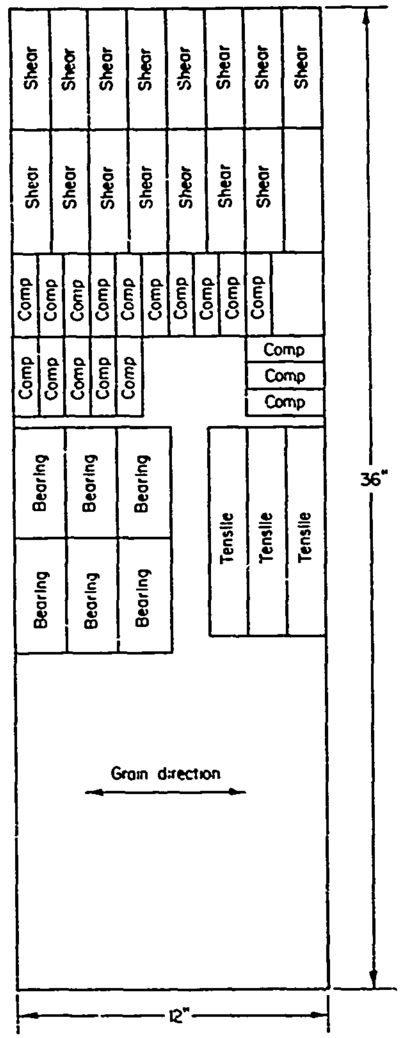

Figure 34. Location of Test Specimens, 0.050 and 0.080-inch Thick Sheet

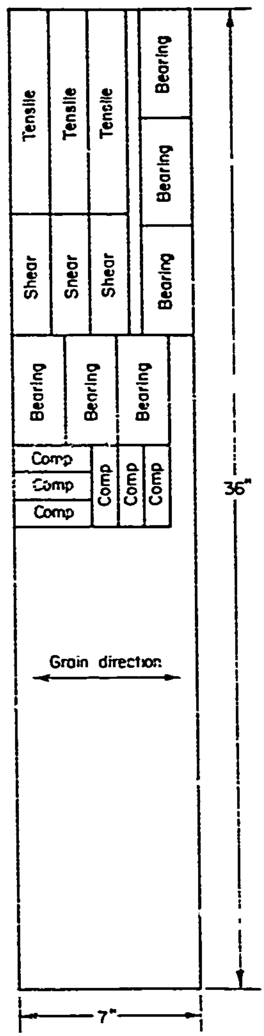

Figure 35. Location of Test Specimens, 0.090-inch Thick Sheet

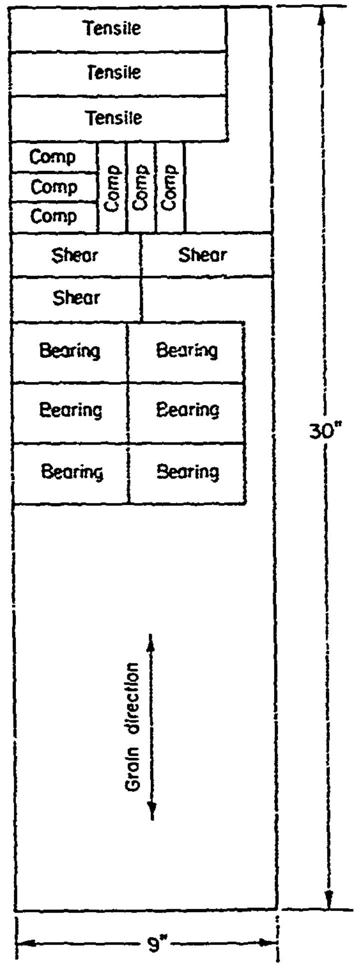

Figure 36. Location of Test Specimens, 0.100-inch Thick Sheet

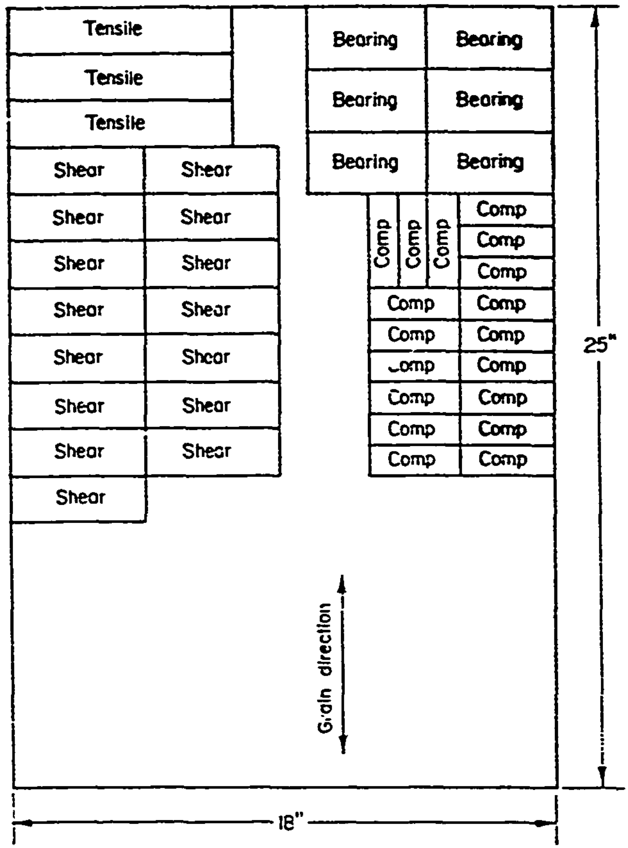

Figure 37. Location of Test Specimens, 0.125-inch Thick Sheet

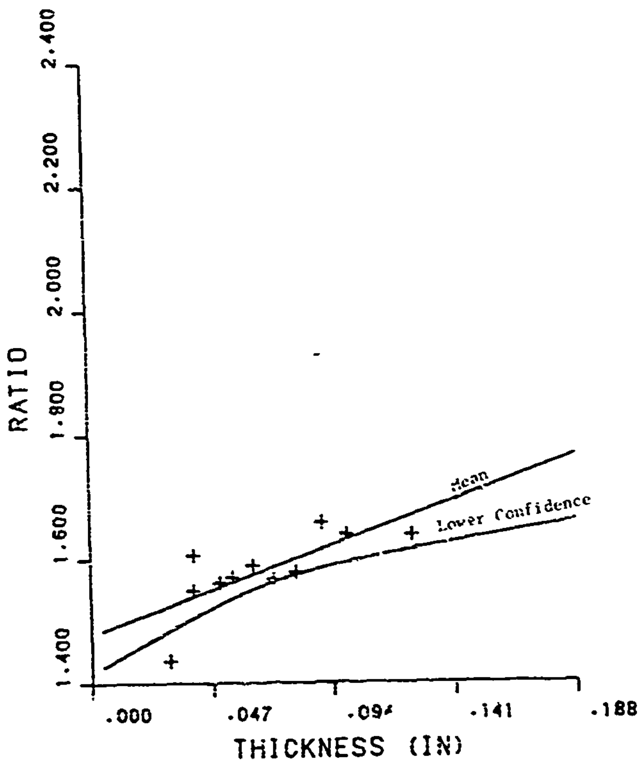

Figure 38. Plot of BUS(LT)/TUS(LT), e/D = 1.5, Ratios

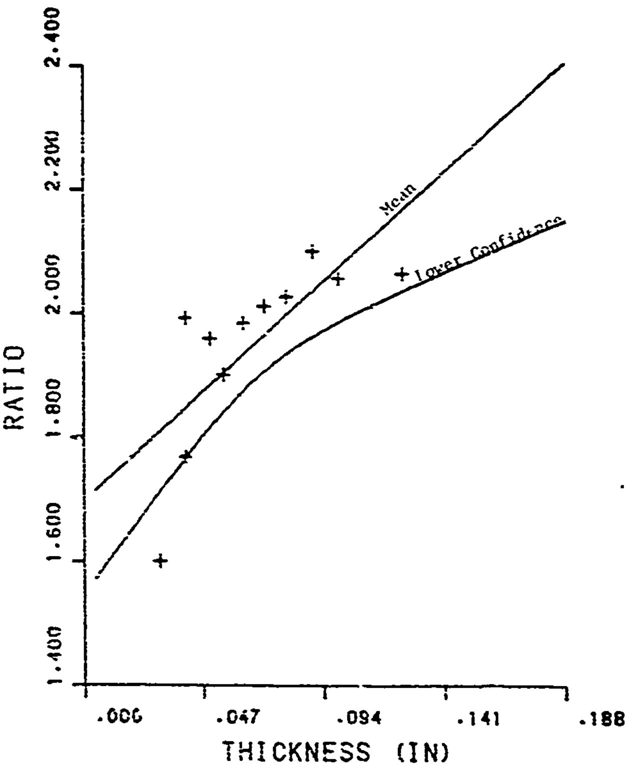

Figure 39. Plot of BUS(LT)/TUS(LT), e/D = 2.0, Ratios

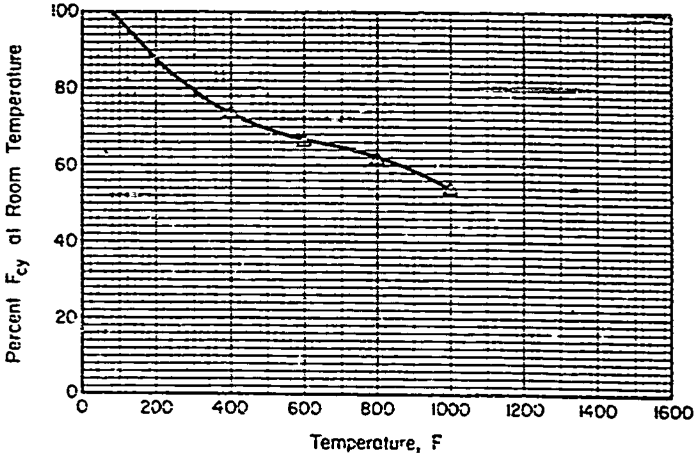

Figure 40. Working Curve Showing the Effect of Temperature on Compressive Yield Strength of Ti-6Al-2Sn-4Zr-2Mo Duplex Annealed Sheet

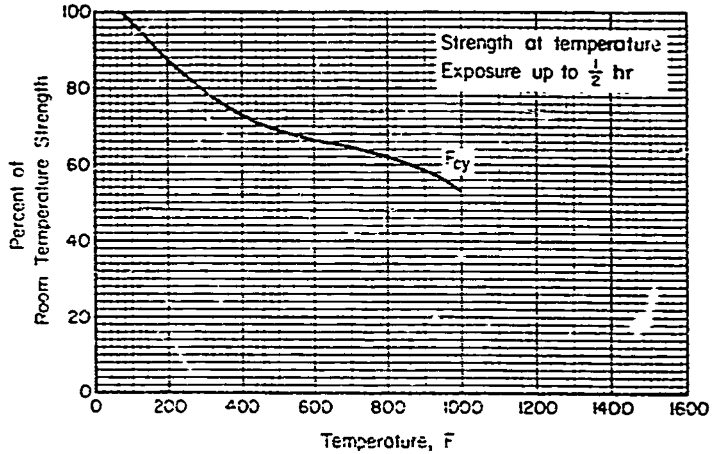

FIGURE 5.3.3.2.1. Effect of temperature on the compressive yield strength (F_{cy}) of duplex annealed Ti-6Al-2Sn-4Zr-2Mo alloy sheet.

Figure 41. Proposed MIL-HDBK-5 Figure 5.3.3.2.1

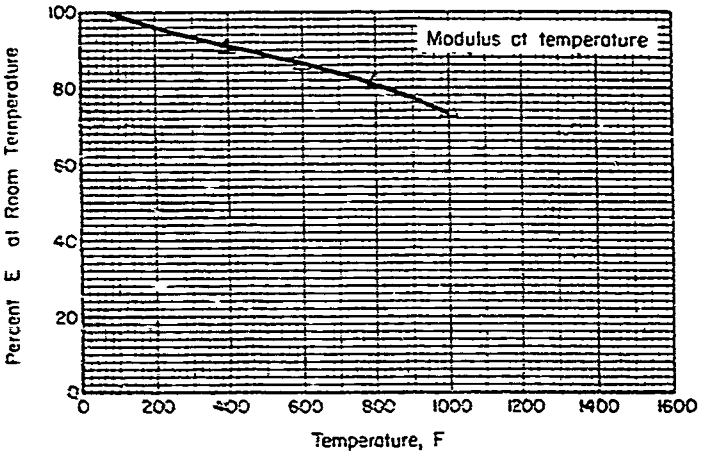

Figure 5.[illegible].— Effect of temperature on the tensile modulus (E) of single, duplex, and triplex annealed Ti-6Al-2Sn-4Zr-2Mo alloy.

Figure 42. Comparison of E Percentages with Existing E Curve

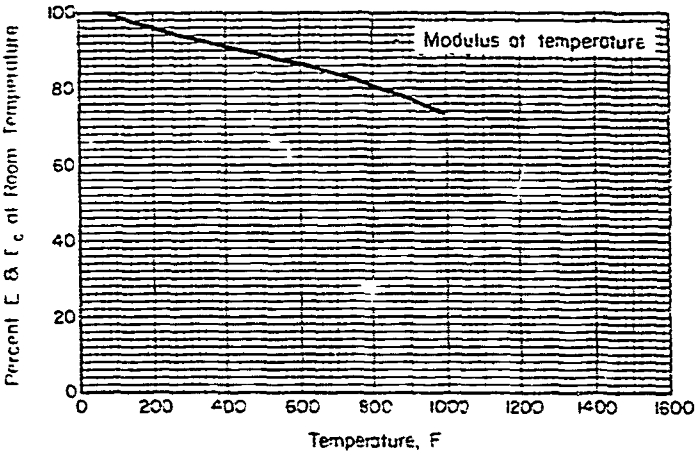

Figure 5.3.3.1.4. Effect of temperature on the tensile and compressive moduli (E and E_c) of single, duplex, and triplex annealed Ti-6Al-2Sn-4Zr-2Mo alloy.

Figure 43. Proposed MIL-HDBK-5 Figure 5.3.3.1.4

APPENDIX A

TEST PROCEDURES

Tension

Procedures used for tension testing were those recommended in ASTM Method E8 and E21. Tensile tests were conducted using Baldwin Universal-type testing machines. These machines are calibrated at frequent intervals in accordance with ASTM Method E4 to assure loading accuracy to within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

The extensometers used conformed to ASTM E83 classification B1 having a sensitivity of 0.0001 in./in. The strain rate in the elastic region was maintained at 0.005 in./in./min. After yielding occurred, the rate was increased to approximately 0.1 in./in./min. until fracture. Ultimate strength, yield strength (0.2 percent offset), and elongation were determined. The yield strength was determined from the load-strain curves. Tensile tests were conducted at room temperature only.

Compression

Procedures for conducting compression tests conformed to ASTM Method E9 along with the temperature control provisions of E21. Specimens tested at elevated temperatures in the Baldwin universal testing machines were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature. Chromel-Alumel thermocouples were attached to the specimen gage section and used to monitor temperatures. For sheet specimens, thermocouples were approximately 1/16 inch from edge of specimen. Each specimen was soaked at temperature for about 20 minutes before being tested. Extensometers and strain rates were similar to those described in tension testing section. The compressive yield strength (0.2 percent offset) was derived from the load-strain curves.

Shear

Shear tests were performed in a Baldwin universal-type testing machine. Shear tests were conducted at room temperature only.

Bearing

Bearing tests were conducted in accordance with ASTM Method E238. All bearing tests were performed in electrohydraulic servocontrolled testing machines. Deformation of the bearing hole was measured with a differential-transformer extensometer and recorded versus load with a conventional autographic recorder. The hardened steel bearing pin was rotated so that a new

bearing surface was used for each specimen. Prior to testing, the pins, specimens, and fixture were ultrasonically cleaned in acetone. After cleaning, white gloves were used in the handling of pins, specimens, and fixtures. Bearing ultimate strength and bearing yield strength (2 percent of pin diameter offset) were determined from the load-strain curves. Bearing tests were conducted at room temperature only.

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